

**Behavioural Economic Applications to Climate Change
Mitigation and Adaptation**

Public Good Games and Risk Experiments

Kerri Brick

Submitted for the degree of Doctor of Philosophy

School of Economics

University of Cape Town

August 2014

Supervisor: Professor Martine Visser

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

Abstract

This thesis contributes to the economics of climate change by incorporating insights from behavioural economics. As both mitigation and adaptation are components of any climate change strategy, the four papers presented here use laboratory and field experiments to examine different dimensions of individuals' mitigation and adaptive behaviour.

The papers in **Section 1** utilise framed public good games to focus on two different aspects of the public goods dilemma synonymous with climate change mitigation. In this context, the first paper '**What is fair? An experimental guide to climate negotiations**' examines the degree to which the use of particular burden-sharing principles in multilateral climate change negotiations reflects self-interest. The multi-country public good game is conducted with a sample of individuals from the United States, European Union, China, India and South Africa. The results signal the use of the historical and future polluter-pays rules by American and Chinese participants to reflect self-interest.

The potential for groups of heterogeneous individuals to meet a collective emission-reduction target through individual contributions is examined in the second paper: '**Cooperation and Climate Change: Can Communication Facilitate the Provision of Public Goods in Heterogeneous Agents?**' Heterogeneity is framed as differences in participants' marginal abatement costs. While communication promotes cooperation, even when heterogeneity is present, the non-binding nature of communication results in the two dominant contribution strategies of free-riding and perfect-cooperation.

The papers in **Section 2** examine the role of risk and uncertainty in individuals' adaptive strategies. The correlation between risk attitudes and individuals' flood adaptation strategies is examined in the third paper: '**Risk Attitudes and Adaptation: Experimental Evidence from a Flood Prone Urban Informal Settlement in South Africa.**' Risk attitudes are elicited from a series of lottery tasks conducted across a sample of individuals living in a flood-prone urban informal settlement. The results indicate that individuals adopting more effective (and costly) adaptation strategies are more risk averse.

The fourth paper '**Risk Preferences, Technology Adoption and Insurance Uptake**' uses lottery tasks and a framed insurance game to examine whether the provision of a framed index insurance product induces individuals to opt into riskier but potentially more profitable activities. Experiment participants are small-scale and subsistence urban food growers. The results indicate that risk-averse individuals are more likely to opt into traditional agriculture and are less likely to use modern farming inputs that require financing.

Preface

I would like to acknowledge financial support from various sources: the Swedish International Development Cooperation Agency (Sida) through the Environment for Development (EfD) Initiative, Environmental Economics Unit, University of Gothenburg; the Carnegie Corporation of New York; the Vice-Chancellor's Strategic Fund, University of Cape Town; and finally, the Center for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria.

My heartfelt thanks to my supervisor, Martine Visser, whose insightful comments and valuable suggestions have guided and shaped this thesis. I would also like to thank Tony Leiman, Mare Sarr and Edwin Muchapondwa from the Environmental-Economics Policy Research Unit (EPRU) who have offered insights and encouragement along the way.

A big thank you to Glenn Harrison, Elisabet Rutström and Morten Lau for the invaluable training and discussion during the workshop on the *Behavioural Econometrics of Risk and Time Preferences*, hosted by the Research Unit in Behavioural Economics and Neuroeconomics (RUBEN), but more broadly, for their generosity and willingness to share with students the mechanics of estimating maximum likelihood models of utility functions in Stata. Additionally, my gratitude goes to CEEPA affiliates, David Starrett, Joseph Cook, Marty Luckert, Rashid Hassan and Margaret Chitiga, for invaluable comments and discussion during CEEPA's research and training workshops. Finally, my appreciation goes to Yonas Alem and other participants at the 7th Annual EfD conference for helpful comments and suggestions.

Far from working in isolation, this thesis has benefitted enormously from the discussions and inputs of my fellow PhD candidates. In particular, I am grateful to Johane Dikgang, Reviva Hassan and Gabi Sulcas for their support, encouragement and friendship.

I owe a debt of gratitude to family and friends who have supported me these past few years. While too numerous to mention, I would like to single out Mark Smith, Adele Serman, Keile Gross and Daniel and Simone Serman.

My deepest acknowledgement to my parents, Maureen and Stanley Brick, whose encouragement, support and belief in me are unwavering.

Finally, a huge (but insufficient) thank you to my husband, Joel Serman. You took every step with me on this journey. This would not have been possible without your support, advice, encouragement and great sense of humour. If any credit is due, it is yours.

Contents

Abstract.....	i
Preface.....	ii
List of Acronyms	vi
Introduction.....	1
1 Mitigation	1
1.1 What is fair? An experimental guide to climate negotiations.....	4
1.2 Cooperation and Climate Change: Can Communication Facilitate the Provision of Public Goods in Heterogeneous Agents?	5
2 Adaptation	6
2.1 Risk Attitudes and Adaptation: Experimental Evidence from a Flood-Prone Urban Informal Settlement in South Africa	7
2.2 Risk Preferences, Technology Adoption and Insurance Uptake	8
References	10
What is Fair? An Experimental Guide to Climate Negotiations.....	14
1 Introduction	15
2 Literature review.....	19
3 Sample	23
3.1 Students	23
3.2 Practitioners	24
4 Experiment.....	25
4.1 Design.....	26
4.2 Parameters and framing	26
4.3 Treatments	30
4.4 Equilibria and best responses	33
4.5 Procedures	35
5 Results	36
5.1 Experimental results	37
5.2 Regression analysis.....	41
5.3 Meeting the target.....	43
6 Discussion.....	45
References	49
Appendix A. Sample statistics	53
Appendix B. Experiment instructions (extract).....	54
Appendix C. Best response given the cumulative contribution of remaining group members	73

Appendix D. Burden sharing principles	76
Appendix E. Logistic regressions, historical and future polluter-pays principles (marginal effects at the mean)	77

Cooperation and Climate Change: Can Communication Facilitate the Provision of Public Goods in Heterogeneous Agents? 78

1	Introduction	79
2	Literature review	83
3	Framing	86
4	Experiment	88
4.1	Procedures	91
5	Results	94
5.1	Average contributions	94
5.2	The distribution of contributions to mitigation	96
5.3	Average contributions (treatments 2 & 3 pooled)	97
5.4	The distribution of contributions to emissions (treatments 2 & 3 pooled)	99
5.5	Consensus around contribution strategies	103
5.6	Meeting the emission reduction target	105
6	Discussion	105
	References	109
	Appendix A. Sample statistics	113
	Appendix B. Sample statistics	114
	Appendix C. Instructions (excerpt)	115
	Appendix D. Emission reduction	129
	Appendix E. Average contributions	129
	Appendix F. Auxiliary regressions	130

Risk Attitudes and Adaptation: Experimental Evidence from a Flood-Prone Urban Informal Settlement in South Africa 131

1	Introduction	132
2	General background and sample specifics	136
3	Experiment	140
3.1	Procedures	140
3.2	Recruitment	142
4	Estimating risk preferences	142
5	Results	146
6	Discussion	154

References	156
Appendix A. Experiment design	161
Appendix B. Experiment procedures	162
Appendix C. Experiment instructions (loss frame).....	163
Appendix D. Alternate CPT models	171
Appendix E. EUT model.....	172
Risk Preferences, Technology Adoption and Insurance Uptake: a Framed Experiment	174
1 Introduction	175
2 Literature review.....	177
3 A model of risk preferences and insurance	180
4 Sample	181
5 Experimental design	183
5.1 Risk games.....	184
5.2 Insurance games	185
5.2.1 Series 1: TS vs. HYL.....	185
5.2.2 Series 2: TS vs. HYL vs. HYI	186
5.3 Experiment procedures	187
6 Results	189
6.1 Risk attitudes	189
6.2 Risk aversion, insurance and technology adoption	191
7 Discussion.....	198
References	201
Appendix A. Decision sheet.....	205
Appendix B. Instructions (excerpt)	206
Appendix C. CRRA parameters	222
Conclusion	224
References	231

List of Acronyms

CE:	Certainty equivalent
CE _{UL} :	Certainty equivalent (upper limit)
CE _{LL} :	Certainty equivalent (lower limit)
CPT:	Cumulative Prospect Theory
CRRA:	Constant Relative Risk Averse/Aversion
ECU:	Experimental currency units
EDEs:	Experimenter demand effects
EPC:	Equal per capita entitlement to emissions
EPR:	Equal percentage reduction of current emissions
EU:	European Union
EU:	Expected Utility
EUT:	Expected Utility Theory
EV:	Expected value
FPP:	Future polluter-pays rule
HPP:	Historical polluter-pays rule
HY:	High-yielding seeds
HYL:	High-yielding seeds with loan
HYL&I:	High-yielding seeds with loan and insurance
IPCC:	Intergovernmental Panel on Climate Change
MCA:	Marginal cost of abatement
MPCR:	Marginal per capita return
MtCO _{2e} :	Metric tons of carbon dioxide equivalent
ON:	Own nationality
OPT:	Original Prospect Theory
PT:	Prospect Theory
RN:	Random nationality
SA:	South Africa
TK:	Tversky and Kahneman
TS:	Traditional seeds
UNFCCC:	United Nations Framework Convention on Climate Change
US:	United States
WRI:	World Resources Institute

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has described climate change as unequivocal: surface temperatures are rising as concentrations of greenhouse gases increase (IPCC 2013).¹ Likely current-century consequences of climate change include increased frequency and intensity of extreme weather events (heat waves, storms and hurricanes), sea-level rise and altered precipitation patterns (Goulder and Pizer 2006). These changes can, in turn, impact significantly on the well-being of ecosystems, wildlife and humans, through more frequent flooding and droughts and an increase in heat-related illnesses (Stern Review 2006, IPCC 2007). The livelihoods of the poor are likely to be most adversely affected as climate-change-related hazards manifest through a reduction in crop yields, increased food prices and food insecurity, damage to home and property and even displacement (IPCC 2013).

Against this backdrop, this thesis examines the implications of certain insights from behavioural economics for climate change policy. More specifically, any public policy response must address both mitigation and adaption (to be discussed in the proceeding subsections). In this context, the papers in this thesis consider: (i) self-interested use of equity preferences and, more so, the impact of material self-interest on cooperation in the negotiating process; (ii) the effect of heterogeneous mitigation costs on cooperation in meeting a domestic emission-reduction target; (iii) the relationship between risk attitudes and choice of adaptation strategy in the context of uncertainty around the timing and severity of climate variability; and (iv), the relationship between risk attitudes and adaptation when proposed adaptive strategies have uncertain outcomes.

1 Mitigation

Mitigation, in which the sources of greenhouse gas emissions are reduced (IPCC 2014), is a vital component of any strategy addressing climate change.

¹ Where climate change relates to changes in the mean and/or variability of the climate (for example temperature, extreme weather events, precipitation) that persist for an extended duration (typically decades or longer), due in part to anthropogenic activities (IPCC 2013). Note that the United Nations Framework Convention on Climate Change (UNFCCC) (Article 1) attributes climate change directly to human activity – distinguishing it from natural climate variability (UNFCCC, 1992).

Within this context of mitigation, climate change typifies a global collective action problem in as much as the emissions of any agent (an individual, company or country, for example) affect other agents and accumulate in the atmosphere over time, mixing globally (IPCC 2013, Brekke and Johansson-Stenman 2008). More specifically, climate change mitigation exemplifies the collective action problem known as a public good dilemma; specifically, while there is broad consensus that a significant reduction of greenhouse gases is needed to reduce the risk of dangerous climate change, as the benefits of (costly) mitigation are shared equally by all irrespective of individual contribution, there is considerable incentive to free ride (Hasson *et al.* 2010, Brekke and Johansson-Stenman 2008).

The current model for tackling climate change is a top-down approach in terms of which emission reduction targets are first negotiated at multilateral climate talks and then implemented at a domestic level by national governments, through the formulation of climate policy. In both these international and domestic settings, since no single country or individual can adequately provide the public good of mitigation and significant incentives for free-riding tend to prevail, widespread participation is needed for climate policy to be effective (Ringius *et al.* 2002). With respect to the implementation of international environmental agreements, no single supranational authority can enforce cooperation and, in a domestic setting, in instances where cooperation can be enforced through penalties for non-compliance, monitoring, verification and enforcement is costly.

On a global scale, international environmental agreements like the Kyoto Protocol require countries with divergent levels of income and historical responsibility for emissions to agree on how best to distribute an abatement burden and apportion future entitlements to emissions. On a country level, reducing a national greenhouse gas inventory requires a change in behaviour from both industry sectors and individuals, both of which categories are asymmetric as regards income, energy consumption, abatement costs and historical emissions. As such, climate change mitigation is a prime example of a public good dilemma in which stakeholders are heterogeneous.

Furthermore, given the historical responsibility of developed nations for the existing stock of greenhouse gases, combined with both the greater vulnerability of developing economies to climate change as well as their need to pursue developmental objectives, the notion of *equity*

has become a cornerstone of the global climate change debate. Specifically, the 1998 Kyoto Protocol to the UNFCCC in Article 10 exemplifies this sentiment by stating the need for “common but differentiated responsibilities” according to specific “national and regional development priorities” (UNFCCC, 1992).

There is a large behavioural economic literature offering insights into the conditions under which people cooperate, even when it is not in their own self-interest to do so (Brekke and Johansson-Stenman 2008). The experimental evidence indicates that people are, to some extent, concerned with achieving outcomes that they perceive to be fair.² However, several studies also provide evidence of a *self-serving bias*, under which individuals’ judgement of what is fair is often aligned with their own self-interest (Babcock, Wang and Loewenstein 1996, Babcock and Loewenstein 1997 and Babcock *et al.* 1997). In relation to climate negotiations, since different equity principles have different cost implications for different countries, the use of a particular equity principle may be based on fairness considerations or, alternatively, may reflect self-interest (for example to soften the emission-reduction target allocated to your particular country (Lange *et al.* 2007, Lange *et al.* 2010, Ringius *et al.* 2002, Carlsson *et al.* 2013).

Furthermore, and again implying a preference for fairness, the experimental evidence from public good games with symmetric players and sanctioning reflects the contribution norm of equal contributions (Reuben and Riedl 2013).³ However, in a climate change setting characterised by heterogeneity, it is not immediately clear whether individuals will be able to reach consensus on a contribution norm. While communication has been found to be effective in facilitating cooperation in public good games in a homogeneous setting (Gächter and Herrmann 2009), when players are heterogeneous, communication might prove to be counterproductive, emphasising dissimilarities between players and amplifying disagreement, rather than fostering cooperation.

² For example, contrary to theory, people make positive (although often suboptimal) contributions in public good games (Ledyard 1995). Fischbacher *et al.* (2001) and Fehr and Fischbacher (2004) find that cooperation reflects the norm of conditional cooperation which prescribes cooperation if group members cooperate and defection if group members defect. Laboratory experiments also provide evidence consistent with reciprocity, in which subjects reward kind actions toward them and punish unkind actions (Brekke and Johansson-Stenman 2008, Gächter and Herrmann 2009).

³ In games with punishment opportunities, a number of authors have found that punishment increases as the differential between individual contributions and average group contributions widens (Fehr and Gächter 2000, Fehr and Gächter 2002, Anderson and Putterman 2006, Hofmeyr *et al.* 2008, Visser and Burns 2013).

To examine outcomes within this context, the first paper of this thesis “**What is fair? An experimental guide to climate negotiations**” considers the role of equity in multilateral climate change negotiations and, more specifically, the self-interested use of burden-sharing principles. The second paper “**Cooperation and Climate Change: Can Communication Facilitate the Provision of Public Goods in Heterogeneous Settings?**” explores the potential for cooperation in meeting a national emission-reduction target when individuals are heterogeneous. These papers are discussed in more detail in the following subsections.

1.1 What is fair? An experimental guide to climate negotiations

Multilateral climate change negotiations and international environmental agreements are mechanisms through which to coordinate a global response to climate change. In this collective action problem, no single country can unilaterally provide the public good of mitigation, no supranational authority exists to enforce cooperation, and countries are incentivised to free-ride given the public good characteristics of climate change mitigation (Brekke and Johansson-Stenman 2008, Lange *et al.* 2010). As such, where voluntary cooperation across countries is needed to reduce emissions, equity principles are commonly used in multilateral climate negotiations to guide the discourse (Lange *et al.* 2007). While choice of burden-sharing principle purportedly reflects negotiators’ fairness ideals, because the application of different equity principles translates into different financial costs and reduction obligations, the use of equity principles likely also reflects economic self-interest (Ringius *et al.* 2002).

Under these assumptions, employing a threshold public good game with a climate change framing, real monetary incentives, and drawing on a cross-section of individuals from the United States, the European Union, China, India and South Africa, this multi-country study examines the degree to which the use of burden-sharing principles reflects self-interest. In an initial treatment, participants, who represent the country of which they are a national, choose between various burden-sharing principles. In a subsequent treatment, drawing inspiration from Rawls’ “veil of ignorance”, participants are unaware of which country they represent, and are randomly allocated to a country after making their decision. The burden-sharing principles incorporated into the experiment include the egalitarian rule (equal per capita emissions), the polluter-pays rule, and the sovereignty rule (equal percentage reduction of

current emissions) (Lange *et al.* 2007, Lange *et al.* 2010, Cazorla and Toman 2000, Winkler *et al.* 2001, Ringius *et al.* 2002).

The results reveal the use of the historical and future polluter-pays rule by American and Chinese participants to be consistent with self-interest. Conversely, there is no evidence of self-interested use of burden-sharing principles among European participants. In both treatments (own and random nationality), European participants select the burden-sharing principles that are most costly for the European Union and that are often advocated by negotiators from developing countries.

1.2 Cooperation and Climate Change: Can Communication Facilitate the Provision of Public Goods in Heterogeneous Agents?

Stakeholder participation in domestic policy processes occurs in extremely complex environments amid large divergences in historical energy usage among different sectors of society, party-politics, special-interest lobbying, alternative developmental priorities and environmental objectives and concerns relating to social and distributive justice.

Despite this complexity, the need for public good provision (meeting an emission-reduction target) in this domestic setting is extremely important given that while the current multilateral, top-down, rules-based approach of the Kyoto Protocol assigns each country a quantifiable and binding emission-reduction target, each country formulates and implements its own domestic climate policy agenda. In this context, this article considers the role of communication (and by extension, stakeholder participation) in facilitating success in meeting a national mitigation obligation when a large degree of heterogeneity exists amongst those engaging in the policy process.

To do so, using a linear public good game with a climate change framing, the experiment reported here examines whether groups of heterogeneous individuals can meet a collective emission-reduction target through individual contributions. Heterogeneity is introduced into the experiment by varying players' marginal productivity *to* the public good. In terms of the experiment framing, this means that players have different marginal costs of abatement, meaning that it is cheaper for a particular player type to reduce an additional unit of emissions

relative to another player type. The experiment consists of two treatments: a standard public good game and a communication treatment where participants are able to communicate with their group members in order to discuss how best to meet the target.

While communication is found to improve public good provision, even when heterogeneity is present, the non-binding nature of communication results in significant levels of free-riding. In particular, with the introduction of communication, two dominant contribution norms of free-riding and perfect-cooperation emerge. This outcome emphasises the importance of sanctioning opportunities in ensuring compliance with mitigation obligations.

2 Adaptation

Adaptation, which refers to action taken to prevent or minimise the expected adverse effects associated with climate change, is the sole response to the climactic impacts that will register over the next several decades before mitigation measures have an effect (Stern Review 2006). As such, the unavoidable impacts of climate change must also be addressed through adaptation policy (EU 2009).

While there is now broad consensus regarding the consequences of climate change, there is continued uncertainty around the timing and severity of climate change impacts (IPCC 2013). Accordingly, responding to the risks inherent in climate change (through adaptation) involves decision-making under uncertainty.

In addition to the uncertainty characterising the adverse impacts of climate change, proposed adaptation strategies may also have uncertain outcomes. For example, within a developing country context, while the adoption of new farming practices to reduce vulnerability to climate change has the potential to engender significant yield improvements, these practices are also potentially more risky relative to traditional agriculture. Mosley and Verschoor (2005) discuss the risk-induced poverty trap: poor individuals who are risk averse – and thus unwilling to invest in riskier modern inputs – will remain poor, while wealthier individuals who are in a position to better insulate themselves from risk will benefit from technological innovations. With this in mind, any proposed adaptation policy with uncertain outcomes must take into

account individuals' aversion to risk and the manner in which they make choices under conditions of uncertainty (Harrison et al. 2010).

In this connection, the final two papers of this thesis focus on risk aversion and uncertainty in the context of adaptation. The third paper, "**Risk Attitudes and Adaptation: Experimental Evidence from a Flood Prone Urban Informal Settlement in South Africa**" categorises risk attitudes in terms of two popular theories of decision-making under uncertainty (namely: Expected Utility Theory and Prospect Theory), and examines the correlation between risk attitudes and choice of flood adaptation strategy. The fourth and final paper, "**Risk Preferences, Technology Adoption and Insurance Uptake**" explores the potential for index-insurance to induce risk-averse individuals to opt into riskier and potentially more profitable farming practices.

2.1 Risk Attitudes and Adaptation: Experimental Evidence from a Flood-Prone Urban Informal Settlement in South Africa

This study characterises the risk attitudes and, more specifically the relationship between risk attitudes and flood adaptation, of a sample of individuals living in a flood-prone urban informal settlement. Decisions around flood adaptation involve significant stakes. In particular, vulnerability to flood risk – and the associated damage to property and possessions and diminished wellbeing – is partly determined by individuals' choice of adaptation strategy. To examine this relationship further, the object of this paper is to determine the extent to which risk attitudes are correlated with choice of adaptation strategy.

The experiment reported in this paper replicates the design of Harrison and Rutström (2009) in which subjects are provided with 60 lottery tasks and, for each lottery task, choose between two lottery pairs. While the participants partake in either a gain, mixed or loss frame, endowments are used to equalise the payoffs across the frames. Participants also complete a survey, capturing information on their demographic characteristics as well as their attitudes to flood adaptation. The sample consists of 174 individuals living in the BM Section of Khayelitsha, a flood-prone urban informal settlement situated in Cape Town.

The results imply that flood adaptation is correlated with risk preferences. Four flood adaptation strategies are incorporated into the model, ranging along the spectrum from least effective (least costly) to most effective (most costly), namely: opt to do nothing, rely solely on plastic sheeting for waterproofing the floor and/or walls of the dwelling, raise the home above ground using sandbags, pallets or stilts, and finally, slant the roof to facilitate rainwater runoff. The results indicate that participants opting to slant their roofs are more risk-averse relative to their counterparts who opt for the remaining strategies.

2.2 Risk Preferences, Technology Adoption and Insurance Uptake

Subsistence farmers in developing countries who are dependent on rain-fed crop production as a livelihood source are extremely vulnerable to climate variability. This vulnerability is exacerbated by widespread poverty and limited access to credit and insurance markets. Amid these circumstances, key factors in the slow rate of technology diffusion in developing countries include risk aversion and imperfect credit and insurance markets (Giné *et al.* 2008, Giné and Yang 2009, Humphrey and Verschoor 2004).

Farmers' investment behaviour is constrained in environments where they lack access to the credit facilities necessary to finance new farming practices, with a number of studies showing adoption of new farming technologies and inputs to be correlated with wealth (Croppenstedt *et al.* 2003, Cole *et al.* 2013, Giné *et al.* 2008 and Chirwa 2005). However, even in situations where credit is accessible but where access to insurance is limited or non-existent, potential borrowers are deterred from taking loans amid the high costs associated with loan default (for example, in the event of crop failure) (Giné and Yang 2009). More broadly, because modern farming practices are potentially more profitable but also more risky, households attempting to insulate themselves from fluctuations in income might opt to stay with traditional agricultural methods (Dercon and Christiaensen 2011). Risk-averse farmers might therefore opt for lower-yielding, traditional farming technologies that do not require financing (Giné and Yang 2009). As such, the provision of insurance, which minimises the default costs and consumption fluctuations associated with production failure, should, in theory, increase adoption rates among risk-averse farmers.

To disentangle the effects of credit constraints from appetite for risk, the experiment reported in this paper isolates the impact of risk aversion on adoption behaviour in two steps. First, a

framed game is used to identify which farmers choose low-risk, low-yield strategies. Next, the game tests whether the provision of insurance induces those individuals who choose the low-risk strategies in the first part of the experiment to opt into more risky but potentially more profitable activities in the second part. Farmers' risk preferences are also elicited using simple lottery tasks for real monetary prizes.

The results of this experiment indicate that risk aversion is negatively correlated with adoption of new farming technologies. Specifically, within the context of the framed simulations, individuals who are more risk averse are less likely to opt into insurance relative to traditional farming strategies. These results provide empirical support for the risk-induced poverty-trap argument, and contribute to the debate around the surprisingly low uptake of index insurance products. While the insurance product in this experiment is designed to reduce the loss experienced by the participants in the event of crop failure, it does not remove this loss entirely, reflecting the reality that index insurance does not remove all risk from the production process under real-life circumstances; specifically, even if a particular index insurance product completely removed the production risk associated with rainfall variability, arguably the most important source of production risk for farmers in developing countries, it would not pay out for crop damage derived from other factors (such as pests), known as basis risk (Barrett *et al.* 2007). Thus, in order to overcome risk aversion among poor individuals stuck in the poverty cycle, and to facilitate the uptake of insurance products, basis risk and residual production risk not accounted for by the insurance product must be addressed.

References

- Anderson, C., Putterman, L. 2006. Do non-strategic sanctions obey the law of demand? The demand for punishment in the voluntary contribution mechanism. *Games and Economic Behaviour* 54:1 – 24.
- Babcock, L., Wang, X., Loewenstein, G. 1996. Choosing the Wrong Pond: Social Comparisons in Negotiations that Reflect a Self-Serving Bias. *The Quarterly Journal of Economics* 111(1): 1-19.
- Babcock, L., Loewenstein, G. 1997. Explaining Bargaining Impasse: The Role of Self-Serving Biases. *The Journal of Economic Perspectives* 11(1): 109-126.
- Babcock, L., Loewenstein, G., Issacharoff, S., Camerer, C. 1997. Biased Judgments of Fairness in Bargaining. *The American Economic Review* 85(5): 1337-1343.
- Brekke, A., Johansson-Stenman, O., 2008. The behavioural economics of climate change. *Oxford Review of Economic Policy* 24(2), 280 – 297.
- Carlsson, F., Kataria, M., Krupnick, A., Lampi, E., Lofgen, A., Qin, P., Sterner, T. 2013. A fair share: Burden-sharing preferences in the United States and China. *Resource and Energy Economics* 35: 1 – 7.
- Cazorla, M., Toman, M., 2000. International Equity and Climate Change Policy. *Resources for the Future, Climate Issue Brief No. 27*.
- Chirwa, E. 2005. Adoption of fertiliser and hybrid seeds by smallholder maize farmers in Southern Malawi. *Development Southern Africa*, 22(1): 1-12.
- Cole, S., Giné, X., Tobacman, J., Topalova, P., Townsend, R., Vickery, J. 2013. Barriers to Household Risk Management: Evidence from India. *American Economic Journal: Applied Economics*, 5(1): 104–135.

- Croppenstedt, A., Demeke, M., Meschi, M. 2003. Technology Adoption in the Presence of Constraints: the Case of Fertilizer Demand in Ethiopia. *Review of Development Economics*, 7(1): 58-70.
- Dercon, S., Christiaensen, L. 2011. Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. *Journal of Development Economics*, 96: 159-173.
- European Union, 2009. Adapting to climate change: towards a European framework for action. White Paper. COM. 147.
- Fehr, E., Fischbacher, E., 2004. Social norms and human cooperation. *Trends in Cognitive Sciences* 8(4):185 – 190.
- Fehr, E., Gächter, S. 2000. Cooperation and Punishment in Public Goods Experiments. *The American Economic Review* 90(4):980 – 994.
- Fehr, E., Gächter, S. 2002. Altruistic punishment in humans. *Nature* 415:137 – 140.
- Gächter, S., Herrmann, B., 2009. Reciprocity, culture and human cooperation: previous insights and a new cross-cultural experiment. *Philosophical Transactions: Biological Sciences*, 364(1518): 791- 806.
- Giné, X., Townsend, R., Vickery, J. 2008. Patterns of Rainfall Insurance Participation in Rural India. *The World Bank Economic Review*, 22(3): 539-566.
- Giné, X., Yang, D. 2009. Insurance, credit and technology adoption: Field experimental evidence from Malawi. *Journal of Development Economics*, 89:1-11.
- Goulder, L., and Pizer, W., 2006. *The Economics of Climate Change*. Resources for the Future Discussion Paper 06-06.
- Harrison, G., Humphrey, S., Verschoor, A., 2010, “Choice Under Uncertainty: Evidence from Ethiopia, India and Uganda,” *The Economic Journal*, 120:80 – 104.

- Harrison, G., Rutström, E., 2009, "Expected Utility Theory and Prospect Theory: One Wedding and A Decent Funeral," *Experimental Economics*, 12:133-158.
- Hasson, R., Löfgren, A., Visser, M., (2010). Climate change in a public goods game: Investment decision in mitigation versus adaptation. *Ecological Economics* 70: 331–338.
- IPCC, 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- IPCC, 2014: Summary for Policymakers, In: *Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlomer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Lange, A., Vogt, C., Ziegler, A. 2007. On the importance of equity in international climate policy: An empirical analysis. *Energy Economics* 29:545-562.
- Lange, A., Löschel, A., Vogt, C., Ziegler, A. 2010. On the self-interested use of equity in international climate negotiations. *European Economic Review* 54: 359 – 375.
- Ledyard, J. O., 1995. Public goods: a survey of experimental research. *The Handbook of Experimental Economics*, 2: 111-194.
- Mosley, P., Verschoor, A., 2005, "Risk Attitudes and the Vicious Circle of Poverty," *The European Journal of Development Research*, 17(1):59 – 88.

Reuben, E., Riedl, A., 2013. Enforcement of contribution norms in public good games with heterogeneous populations. *Games and Economic Behavior*, 77: 122-137.

Ringius, L., Torvanger, A., Underdal, A., 2002. Burden Sharing and Fairness Principles in International Climate Policy. *International Environmental Agreements: Politics, Law and Economics* 2, 1 – 22.

Stern Review (Stern review team) 2006. *The economics of climate change*. London, Treasury. http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm.

United Nations Framework Convention on Climate Change, 1992. Treaty Doc No. 102-38, United Nations

Winkler, H., Tyani, L., Spalding-Fecher, R., 2001. What could potential carbon emissions allocation schemes and targets mean for South Africa? *Energy and Development Research Centre Report Series*, University of Cape Town.

What is Fair? An Experimental Guide to Climate Negotiations

Kerri Brick and Martine Visser^φ

Abstract

International commitments to reduce emissions should ideally be negotiated between countries in a manner considered to be fair or equitable. While the burden-sharing principles commonly advocated in climate negotiations reflect different views of what constitutes a fair way to distribute the abatement burden, their use can also be strategically motivated to legitimise a specific bargaining position. In this context, using a threshold public good game with a climate change framing, real monetary incentives and drawing on a sample of individuals from the United States, the European Union, China, India and South Africa, this multi-country study examines the degree to which the use of burden-sharing principles reflects material self-interest. In an initial treatment, participants, who represent the country of which they are a national, choose between various burden-sharing principles. In a subsequent treatment, drawing from Rawls' veil of ignorance, participants are unaware of which country they represent and are randomly allocated to a country after making their decision. A comparison of participants' choices across these two treatments indicates that the use of the historical and future polluter-pays rules by American and Chinese participants is consistent with material self-interest, or, in other words, self-interested use of burden-sharing principles.

Keywords: public good game, multi-country study, multilateral climate negotiations, fairness

^φ Extreme gratitude goes to the following persons for helping to recruit subjects and/or arrange payment of experiment payoffs: Maria Damon (New York University); Salvatore Di Falco (London School of Economics); Gautam Gupta and Abhishek Das (Jadavpur University); Jintao Xu and Li Ling (Peking University).

1 Introduction

Climate science indicates that a significant reduction of greenhouse gases is needed to reduce the risk of catastrophic climate change. Multilateral climate change negotiations, such as the United Nations Framework Convention on Climate Change (UNFCCC), and international environmental agreements, such as the Kyoto Protocol, are mechanisms through which to coordinate a global response to climate change. In this collective action problem, no single country can unilaterally provide the public good of mitigation, no supranational authority exists to enforce cooperation and countries are incentivised to free-ride given that while there is a private cost associated with mitigation, the benefits are shared equally between all countries (Brekke and Johansson-Stenman 2008, Lange *et al.* 2010). In this setting, where voluntary cooperation across countries is needed to reduce emissions, climate negotiators must reach consensus on emission-reduction targets that are considered by the majority to be fair or equitable (Ringius *et al.* 2002).

Within this context, equity is an important subtext of the climate change debate with the principle of “common but differentiated responsibilities” (UNFCCC, 1992) shaping the narrative. More specifically, equity principles are commonly used in multilateral climate negotiations to guide the formulation of burden-sharing agreements (Lange *et al.* 2007).

While choice of burden-sharing principle purportedly reflects negotiators’ fairness ideals, because the application of different equity principles translates into different financial costs, reduction obligations and carbon entitlements¹, and as negotiators are directed by domestic politics and sentiment, the use of equity principles likely also reflects economic or material self-interest (Ringius *et al.* 2002). In this context, several studies provide evidence of a *self-serving bias* – where individuals’ judgements of what is fair are often aligned with their own self-interest (Babcock, Wang and Loewenstein 1996, Babcock and Loewenstein 1997, Babcock *et al.* 1997, Brekke and Johansson-Stenman 2008). This self-serving bias is of particular interest in the context of multilateral climate change negotiations where, as multiple burden-sharing principles can conceivably be advocated by a particular country, there is room for self-interested use of burden-sharing principles within a large set of legitimate equity

¹ Also referred to as the “*right to emit*” (Winkler *et al.* 2001).

arguments (Ringius *et al.* 2002). In this way, negotiators may use legitimate-sounding burden-sharing principles to prevent their country being assigned a legally binding reduction target or, at the very least, to minimise the target (Lange *et al.* 2007, 2010).

While there is a large body of literature reviewing the equity principles most commonly advocated during climate negotiations and assessing their implications at the country-level (Ringius *et al.* 1998, Cazorla and Toman 2000, Ringius *et al.* 2002, Torvanger and Ringius 2002, Torvanger and Godal 2004, Winkler *et al.* 2001; see Carlsson *et al.* 2013 for a discussion), few studies elicit preferences for burden-sharing principles (with the exception of Lange *et al.* 2007, Lange *et al.* 2010 and Carlsson *et al.* 2013).

In this context, the experiment reported here examines the extent to which individuals' use of equity principles reflects material self-interest (in other words, whether individuals use equity principles in a self-serving way). To do so, when playing a threshold public good game with a climate change framing, participants of different nationalities choose between various equity principles, where each equity principle denotes a specific public good contribution. More specifically, the cost rankings of the respective equity principles (in terms of the associated public good contributions) differ across regions: for example, as will be discussed, while the principles of equal per capita emissions and historical polluter-pays are most costly for the United States (specify the largest contribution to the public good), they are least costly for China and India. In an initial treatment, when choosing between the various equity principles, each player represents the country of which they are a national (for example, the payoff function of the United States is relevant for the American participant). In line with the findings of Lange *et al.* (2010) and Carlsson *et al.* (2013), choice of equity principle for American and Chinese players is found to be in line with material self-interest, with both American and Chinese participants opting for equity principles that prescribe the smallest contribution to the public good and are generally synonymous with the largest payoffs.

This result, that choice of burden-sharing principle is (at least partly) derived from material self-interest, is important in the context of multilateral climate negotiations where the equity principle that an agent adheres to will likely affect or shape the negotiating process (and by extension, the negotiation outcome). Against this background, this experiment further examines the impact of self-interest on the negotiating process. To do so, in a second treatment, while participants must once again choose between the various burden-sharing principles, they

do so from behind a veil of ignorance (Rawls 1971), where they no longer know which payoff function is applicable to them. The results indicate that American and Chinese participants are both more likely to select equity principles that prescribe a larger contribution to the public good in the veil-of-ignorance treatment; the outcome of which is greater success in meeting the threshold.

The burden-sharing principles incorporated into the experiment are some of those most commonly found in the literature and advocated in climate negotiations, namely, the egalitarian rule (equal per capita emissions), the polluter-pays rule and the sovereignty rule (equal percentage reduction of current emissions) (Lange *et al.* 2007, Lange *et al.* 2010, Cazorla and Toman 2000, Winkler *et al.* 2001, Ringius *et al.* 2002).²

The experiment draws on a sample of university students and what are referred to as “practitioners”. The term practitioner refers to those individuals who frequently engage with climate change related issues (for example, academics and researchers, individuals from non-governmental organisations and government officials), while students are considered to be more representative of the general public. Five regions are included in the experiment, namely the United States (US), European Union (EU), China, India and South Africa (SA); and each group consists of a national from one of these regions.

Building on the design of Milinski *et al.* (2008) and Tavoni *et al.* (2011), the experiment is designed as a provision point (threshold) public good game. In terms of the structure of the game, participants are provided with an endowment that is to be allocated between a public good or private account, where allocations to the public good are framed as mitigation. When the groups’ total public good contributions equals or exceeds the provision point, which is framed as the threshold for dangerous climate change, public good contributions are multiplied by some factor and divided equally among the players. The setup is thus equivalent to a continuous public good game (Croson and Marks 1998). In terms of the experiment framing, participants are told that because there are no borders in the atmosphere, a reduction in

² The Ability to Pay rule, whereby wealthier countries are responsible for a greater share of the abatement burden (Winkler *et al.* 2001) is also frequently cited in both the literature and negotiations but is omitted from this design. As the experiment was conducted online, in the interests of keeping the design as cognitively simple as possible, the number of equity principles incorporated into the experiment was limited. Equity principles that emphasized fairness considerations as well as generated the largest payoff variation across all players were prioritized for inclusion.

emissions by one country is shared by all countries and, furthermore, that the return from mitigation (the public good) signifies the global benefits synonymous with mitigation, such as reduced climate variability and a reduced probability of environmental disaster.

Conversely, when contributions fail to meet the threshold, players do not receive any return from contributions to the public good. Additionally, players representing developed countries lose 25% of the experimental currency units (ECUs) allocated to the private account while developing countries lose 50%. Once again, in terms of the framing, it is assumed that mitigation was not sufficient to subvert the negative effects of climate change and that each player (region) is obliged to use a portion of the funds in his or her private account for adaptation and to fund disaster relief. Developing countries will need more severe adaptation and disaster relief measures and thus lose a greater portion of ECUs from their private accounts. With respect to the design, the cost rankings (in terms of contributions to the public good) of the equity principles differ among the regions included in the experiment (for example, the historical polluter-pays principle is more costly for developed countries and thus prescribes a larger public good contribution for the US and EU relative to China, India and SA).

Lange *et al.* (2010) notes that, because the financial cost associated with each equity principle differs among regions (in other words, the cost ranking of equity principles differs among regions), self-interested use of burden-sharing principles necessitates that different regions support different equity principles to different degrees. As such, it was important to include both these elements (different cost rankings and different regions) into the design.

Broadly, the estimation results reveal that the use of the historical and future polluter-pays rule by American and Chinese participants is consistent with material self-interest. Specifically, when representing the US, American participants are less likely to select the principle of historical polluter-pays relative to other nationalities; however, this effect disappears when participants are randomly allocated to a country. Chinese participants are less likely to select the principle of future polluter-pays when representing their own nationality, but this effect also dissipates when the participants are randomly assigned a country. Furthermore, when representing the country of which they are a national, the majority of American and Chinese participants favour the least costly burden-sharing principles. Conversely, there is no evidence of self-interested use of burden-sharing principles among European and Indian participants. In both treatments (own and random nationality), European participants in particular select the

burden-sharing principles that are most costly for the EU and that are often advocated by negotiators from developing countries.

The paper proceeds as follows: a literature review is provided in Section 2, while Section 3 provides a description of the sample. The experiment design is outlined in Section 4. The results are provided in Section 5, while Section 6 concludes with a discussion.

2 Literature review

In the context of multilateral climate negotiations, a central point of contention surrounds how to share a given abatement burden (Dannenberg *et al.* 2010). With an incentive for free-riding, the absence of a supranational authority to enforce cooperative behaviour, and the need for widespread participation, negotiators are faced with the challenge of finding a burden-sharing scheme that is considered to be “fair” by a majority of governments (Ringius *et al.* 2002). Experimental evidence indicates that people are concerned about being fair to others and about others being fair to them. For example, contrary to theory, people make positive (although often suboptimal) contributions in public good games (Ledyard 1995).³

Dannenberg *et al.* (2010) consider whether climate negotiators have a personal preference for equity by measuring the inequity aversion of a sample of individuals involved in climate policy, using a multi-country (online) experiment. The authors find that participants are averse to both advantageous and disadvantageous inequality. Overall, the authors do not find inequity aversion to be correlated with nationality and conclude that equity preferences (within similar groups of people) are not greatly influenced by cultural circumstances.

Lange *et al.* (2007) analyse the importance of equity principles via an online survey of individuals of different nationalities who are involved in climate policy. While all participants consider equity in international climate negotiations to be important, participants from poorer countries place greater importance on the role of equity (relative to individuals from wealthier

³ Fischbacher *et al.* (2001) and Fehr and Fischbacher (2004) find that cooperation reflects the norm of conditional cooperation which prescribes cooperation if group members cooperate and defection if group members defect. Laboratory experiments also provide evidence consistent with reciprocity, in which test subjects reward kind actions toward them and punish unkind actions (Brekke and Johansson-Stenman 2008, Gächter and Herrmann 2009). In games with punishment opportunities, a number of authors have found that punishment increases as the differential between individual contributions and average group contributions widens (Fehr and Gächter 2000, Fehr and Gächter 2002, Anderson and Putterman 2006, Hofmeyr *et al.* 2008, Visser and Burns 2013).

countries). In terms of preferences for specific equity principles, the authors find evidence of pure economic self-interest. Specifically, respondents from wealthier countries are less in favour of the polluter-pays and ability-to-pay rules (relative to poorer countries). In a subsequent paper, Lange *et al.* (2010) analyse respondents' perceptions of the negotiating positions taken by the US, EU, G77/China and Russia. In particular, respondents are asked the extent to which each region is (in their opinion) expected to support each burden-sharing principle. Overall, the authors find the perceived support of equity principles by a particular region to be in line with economic self-interest. Specifically, the authors find that the cost rankings of the respective equity principles (ranking of financial cost of each equity principle for a particular region) are significantly (and negatively) related to their perceived support by the US, EU and Russia (there was no significant relationship for G77/China), signalling economic costs to be a major determinant of perceived use of equity principles by climate negotiators.

Carlsson *et al.* (2013) use a choice experiment to investigate preferences (willingness to pay) for various burden-sharing principles among individuals in the US and China. Overall, in line with self-interested use of burden-sharing principles, respondents are found to favour the rule that is least costly for their country.

The results reported in this article support the findings of both Lange *et al.* (2010) and Carlsson *et al.* (2013).

The design of the public good experiment reported here draws on the work of Milinski *et al.* (2008) and Tavoni *et al.* (2011) who both use threshold public good games to consider the social dilemma synonymous with climate change.

Milinski *et al.* consider whether a group of individuals are able to collectively reach a target through individual contributions when the whole group suffers when the target is not reached. The authors design a provision point (threshold) public good game where failure to reach the threshold is interpreted as failure to prevent dangerous climate change. Participants, who are each endowed with €40, can contribute either €0, €2 or €4 to the public good (framed as a climate account and synonymous with investment in climate change mitigation) in each of ten rounds. If total contributions after all ten rounds reach or exceed €120 (the threshold), participants keep the remainder of their endowment not spent on mitigation. Conversely, failure

to meet the threshold means that players lose all of their remaining endowment with varying probability (with 90%, 50% and 10% probability over different treatments). While players are informed of the contributions of other group members after each round, they are unable to communicate with one another. The authors find that groups facing a higher probability of losing their private-account savings are more successful in meeting the collective target; however, only 50% of groups met the threshold in the 90% treatment.

The social dilemma implicit in the game (as in the game reported here) is that the more a player invests, the greater the likelihood of her group reaching the target, but the less guaranteed savings she retains in her private account. In addition, the greater the contributions from her group members, the less she needs to individually invest to guarantee reaching the target.

Tavoni *et al.* extend the design of Milinski *et al.* by incorporating endowment heterogeneity and communication to examine the impact of inequality on cooperation and the extent to which communication is able to mitigate the anticipated negative effect. In the event the threshold is not met, all players face a 50% probability of losing the funds in their private accounts. Once again, players are informed of their group members' contributions after each round. Endowment inequality is incorporated into the design via three inactive rounds at the start of the game where players' contributions are randomly determined: in the symmetric treatment, all players contribute €2 per round while, in the asymmetric treatment, half the group contributes €0 or €4 per round, respectively. In the asymmetric treatment, rich and poor players enter the fourth round with €40 and €28, respectively. In certain treatments, at different intervals over the ten rounds, players were able to make non-binding announcements with respect to their intended contribution level. The results signal that inequality negatively impacts on coordination success – with a smaller portion of groups meeting the threshold in the asymmetric treatment when compared to the symmetric treatment. With the introduction of the non-binding announcements, the proportion of asymmetric groups meeting the threshold tripled and did not differ significantly to that of the symmetric groups.⁴

⁴ The primary focus of the experiment reported here is to examine the extent to which individuals' use of equity principles reflects self-interest and to consider the impact of self-interest on the negotiating process. Ultimately, we examine how equity principles shift across the two treatments (when players move from a known to unknown payoff function). As such, we do not incorporate communication into the design; however, considering the role of communication in facilitating coordination would be a natural extension of the current design.

The experiment reported here differs in several aspects from the design of Milinski *et al.* and Tavoni *et al.* Firstly, their design is structured around avoiding a public bad whereby participants contribute to the public good to avoid a probabilistic loss (if the target is met). In this setup, players do not receive a return from the public good and therefore do not derive a benefit from contributions in excess of the threshold. In the experiment reported here, players do earn a return from the public good (in the advent that the threshold is met), quantifying the benefits associated with a reduced risk of dangerous climate change.

Secondly, as the focus of this paper relates to how preferences for equity principles shift under different circumstances (specifically when nationality is known versus unknown) and not the dilemma between immediate action and future consequences, this game is designed as a one-shot public good game.

Thirdly, as this game is concerned with individuals' preferences for specific burden-sharing principles and the extent to which these preferences reflect fairness or self-interest, the framing was more extensive.⁵ For example, the endowment inequality introduced into the game was not randomly assigned to players as in the case of Tavoni *et al.*, but is framed to reflect disparities in the levels of wealth of the regions included in the design. Furthermore, the contribution levels associated with each burden-sharing principle were derived from emissions data reported by the World Resources Institute (WRI) (discussed in a subsequent section).

Fourthly, instead of losing their savings with some probability, players are guaranteed to lose a portion of the funds in their private account. However, this portion differs for players representing developed and developing countries (signalling the greater vulnerability of developing countries to climate change).

⁵ With respect to framing, several studies show that adding context (framing) to experiment instructions significantly alters the results (Eckel and Grossman 1996, Lieberman *et al.* 2004, Burnham *et al.* 2000). More specifically, Eckel and Grossman (1996) argue that in order to introduce the social and psychological factors that affect economic decision making, abstraction needs to be (to some extent) abandoned. Lowenstein (1999) argues that the external validity of experimental results can be enhanced when appropriate context is added. In a climate change context, individuals are extremely divided on who bears the responsibility (and therefore cost) of reducing emissions. In addition, climate change discourses become extremely emotionally charged and clouded by issues of social and distributive justice. As such, as opposed to using abstract terminology, the framing used in this experiment enables subjects to draw on their own subjective (and country specific) perceptions around climate change mitigation when deciding their choice of equity principle.

Finally, Dannenberg *et al.* (2011) consider the impact of threshold uncertainty on coordination in a threshold public good game. The authors find that threshold uncertainty impacts negatively on public good provision. More broadly, Barrett (2012) discusses the detrimental effect of threshold uncertainty on the success of collective action. As the focus of this paper is how preferences for burden-sharing principles shift with the introduction of the veil of ignorance, we do not incorporate threshold uncertainty into the design and instead assume the threshold to be certain.

3 Sample

As previously mentioned, the experiment draws on a sample of university students from the US, EU, China, India and SA as well as a small sample of “practitioners” (academics and researchers, individuals from non-governmental organisations and government officials) from the same countries. Sample statistics for both groups are provided in the sub-sections that follow.

3.1 Students

Sample statistics are reflected in table 1. A total sample of 269 university students was recruited from: New York University (US) (51 students), The London School of Economics (EU) (51 students),⁶ Peking University (China) (56 students), Jadavpur University (India) (60 students) and the University of Cape Town (SA) (51 students). In order to equalise the number of students from each nationality, five Chinese and nine Indian participants (the last to submit their questionnaires) were excluded from the sample, leaving a sample of 255 students (51 groups comprising 5 nationalities each).

Students were recruited via advertisements which were placed on announcement boards in various university departments (Jadavpur), published in a monthly student newsletter (LSE), advertised on Twitter and online classifieds (NYU) and other social network platforms (UCT and PKU).

⁶ One student was studying at the University College London

On average, subjects were 23 years old and around 45% were male – although this varied considerably according to country, particularly in the US and SA, where 75% and 71% of participants respectively were female.

Table 1. Sample statistics (students)

	Subjects n=255	US n=51	EU n=51	China n=51	India n=51	SA n=51
Gender						
Male	0.45	0.25	0.55	0.35	0.37	0.29
Female	0.55	0.75	0.45	0.65	0.63	0.71
Age	23.04 (3.48)	26.35 (4.91)	23.06 (2.96)	22.53 (2.18)	21.84 (1.88)	21.39 (2.11)

Note: Standard deviations in parentheses

As is evident from Appendix A, the students are also from a broad range of faculties. Overall, 23% of students were economics majors (although 73% of Indian participants were studying economics).⁷ In addition, only 5% of participants were studying environment-related subjects.

3.2 Practitioners

A database of practitioners was compiled using online attendance lists from meetings and workshops hosted by the Intergovernmental Panel on Climate Change (IPCC) and the UNFCCC. In addition, contact details were sourced from directory lists from government websites and university research centres.

A total of 70 practitioners participated in the study (14 individuals from each of the represented nationalities). As appears from table 2, on average, practitioners were around 32 years of age and 57% were male. Just over 60% were in academia (academic staff, PhD students and post-docs involved in climate-related research)⁸, although this figure was 29% for South Africa. One-fifth of the sample worked in non-governmental organisations (NGOs), while the remainder was employed in the private sector or government organisations, although here too there was considerable variation across countries.

⁷ Despite the Indian student sub-sample being largely comprised of economic students, there is very little evidence of interest-based bargaining among Indian students.

⁸ Note that some of the PhD students and post-docs were studying abroad at the time of completing the online experiment

Table 2. Sample statistics (practitioners)

	Subjects n=70	US n=14	EU n=14	China n=14	India n=14	SA n=14
Gender						
Male	0.57	0.64	0.71	0.43	0.64	0.43
Female	0.43	0.36	0.29	0.57	0.36	0.57
Age	32.20 (7.22)	34.21 (11.09)	32.21 (3.62)	33.07 (7.05)	30.29 (7.10)	31.21 (5.51)
Sector						
Academia	0.61	0.57	0.79	0.64	0.77	0.29
NGO	0.20	0.29	0.21	0.14	0.23	0.14
Government	0.06	0.07	0.00	0.14	0.00	0.07
Private Sector	0.13	0.07	0.00	0.07	0.00	0.50

Note: Standard deviations in parenthesis

As anticipated, given the recruitment strategy, the majority of practitioners were employed in an environment-related field. Many of them were active in climate policy analysis and research.

4 Experiment

The experiment reported here utilises a threshold public good game with a climate change framing to test for evidence of strategically-motivated use of burden-sharing principles. The instructions provided to participants are replicated in Appendix B.

The design takes cognisance of the fact that parties to multilateral climate negotiations are heterogeneous in terms of wealth, historical absolute emissions, per capita emissions, projected future emissions and vulnerability to climate change, and that these asymmetries would be likely to cloud arguments around what is considered to be the fairest way to distribute the burden. As such, as will be discussed in the following subsection, heterogeneity is incorporated into the experiment design.

The subsection that follows briefly outlines the experimental design while the framing and motivation behind the design are discussed in detail in section 4.2.

4.1 Design

Each group consists of n players. Furthermore, each participant is provided an endowed, y_i , which is allocated between a public and a private account, where c_i denotes subject i 's contribution to the public account and g_j reflects the allocation to the public account by the group. When g_j exceeds some threshold, T , every experimental currency unit (ECU) allocated to the public account generates a return of α_i for each group member, where $0 < \alpha_i < 1$, while each ECU contributed to the private account generates a return of β_i , where $\beta_i = 1$. Subject i 's earnings are reflected as:

$$\pi_i = \beta_i(y_i - c_i) + \alpha_i(g_j) \quad \text{if } g_j \geq T \quad (1)$$

When the group's contribution to the public account, g_j , does not exceed threshold T , participants in that particular group do not earn a return from investing in the public account ($\alpha_i = 0$). In addition, each group member retains only a portion, λ_i , of the ECUs allocated to their private account, where $0 < \lambda_i < 1$. In the case that the threshold is not met, subject i 's earnings are reflected as:

$$\pi_i = \beta_i(y_i - c_i)\lambda_i \quad \text{if } g_j < T \quad (2)$$

4.2 Parameters and framing

Each group of five consists of one participant each from the *US, EU, China, India and SA*. Collectively, in 2006, these countries accounted for around 62% of global CO₂ emissions (WRI, 2010). While the US and EU are historically responsible for the accumulation of greenhouse gases in the atmosphere, China and India, both rapidly growing economies, are likely to be large future emitters. In fact, China has overtaken the US as the largest current emitter and, in 2006, accounted for nearly 22% of global CO₂ emissions (WRI 2010).

However, while emerging economies are likely to be major future emitters, per capita emissions are significantly higher in developed economies. For example, per capita CO₂ emissions in the US (in 2006) were 19.3 MtCO₂e as compared to 4.7 MtCO₂e for China and 1.2 MtCO₂e for India (WRI 2010). While SA is the largest emitter in Africa, its share of emissions is relatively small in comparison to the other group members (contributing only 1.2%

to global emissions in 2006); however, it has per capita emissions comparable with those of the EU: 7.4 MtCO_{2e} in 2006 as compared to 8.4 MtCO_{2e} for the EU (WRI 2010).

Group emissions

Data reflecting the *groups' emissions* were adapted from emissions data reported by the *Climate Analysis Indicator Tool*, World Resources Institute (WRI 2010). Specifically, annual MtCO_{2e} emission levels⁹ reported by the WRI for the US, EU, China, India and SA were scaled downwards by 100 and reported for the periods: 1980, 1985, 1990, 1995, 2000 and 2006 (table 3). Using the same source and scaling, projected future emissions were also reported for periods: 2010, 2015, 2020, 2025 and 2030.¹⁰ Table 3 was provided to participants.

Table 3. Past, present and projected future emissions (MtCO_{2e})

Country	1980	1985	1990	1995	2000	2006	2010*	2015*	2020*	2025*	2030*
US	47	46	50	52	58	58	57	58	58	58	58
EU	45	42	42	40	40	41	40	40	39	39	38
China	14	18	23	32	33	62	69	88	100	110	117
India	3	4	6	8	10	13	15	18	22	27	33
SA	2	2	3	3	3	3	4	4	4	5	5
<i>Total</i>	<i>111</i>	<i>112</i>	<i>124</i>	<i>135</i>	<i>144</i>	<i>177</i>	<i>185</i>	<i>208</i>	<i>223</i>	<i>239</i>	<i>251</i>

Note: * projected emissions

Source: adapted from Climate Analysis Indicator Tool (WRI 2010)

By using emissions data that proportionately reflect the emission-realities of the countries represented in the study, we are able to ensure that the equity considerations pervasive throughout the climate change discourse are well-reflected in the design. For example, the data illustrate that while developed countries are historically the major emitters, emission levels have peaked in the US and are on a decline in the EU; China has surpassed the US as the world's largest emitter, while emissions from China and India are projected to rise substantially; and, while South Africa's emissions are also projected to rise, South Africa represents a very small share of the group's total emissions.

⁹ Excluding land use changes

¹⁰ Note that projected emissions for South Africa were based on reported projections for Africa.

Endowment

Signalling differences in wealth, heterogeneity is introduced by varying players' endowments (v_i), with developed-country players being allocated more ECUs than their developing-country counterparts. At the start of each treatment, US and EU participants are endowed with 70 ECUs each, Chinese participants are endowed with 50 ECUs and Indian and South African subjects are endowed with 25 and 15 ECUs, respectively.

Mitigation

Participants divide their endowments between a private and public account, where the public account is a *mitigation* account.¹¹ By contributing towards the mitigation account, participants are investing in mitigation. The group's total contribution to the mitigation account (g_i) is multiplied by 1.5 and divided equally amongst the group, yielding $\alpha_i = 0.3$.

In terms of the framing, subjects are told that the total number of ECUs contributed to the mitigation account signifies the group's investment in mitigation. This amount is then multiplied by an emissions factor of 1.5 to determine the emissions reduction of the group.¹²

Threshold

Again, in terms of the framing, participants are told that at a recent climate change summit, policy-makers from the US, EU, China, India and SA pledged to reduce greenhouse gas emissions to 62 MtCO₂ by 2050 (half of the emissions level in 1990) (in order to meet the scientific threshold of keeping the mean global temperature increase below 2° Celsius). It was stressed that no individual country targets had been agreed to. Each participant thus has to decide how much s/he wants to contribute towards meeting this target.

Because 2006 is the most recent year for which actual data are available, it is used as the basis for the group's negotiations. Each group is given the target of reducing emissions by 115MtCO₂

¹¹ Mitigation was explained to participants during the experiment as an approach that decreases the sources of greenhouse gas emissions. An example of using renewable energy sources for electricity generation instead of fossil fuels was provided. Finally, the public good nature of mitigation was emphasized by stating that by lowering the quantity of greenhouse gases in the atmosphere you reduce the severity of climate change. Because there are no borders in the atmosphere, a reduction in emissions by one country is shared by all countries. So everyone in your group will benefit from mitigation.

¹² The following example was provided to the subjects: Assume that your group puts a total of 80 ECUs in the mitigation account. This means that your group has invested 80 ECUs in mitigation. These 80 ECUs are multiplied by an emissions factor of 1.5. This means that your group has reduced emissions by 120 MtCO₂.

by 2050.¹³ Each group thus has to contribute a minimum of 77 ECUs ($g_j \geq 77$) to the public (mitigation) account.¹⁴

Assuming that the target (threshold) is met

If a particular group meets the emission reduction target ($g_j \geq T$), the ECUs in the mitigation account are multiplied by 1.5 and distributed equally between all group members, irrespective of individual contribution. Furthermore, participants keep whatever ECUs they contribute to the private account.

The return from mitigation (α_i) signifies the global benefits synonymous with mitigation and, more specifically, of keeping the temperature increase below 2° Celsius, the scientific threshold for dangerous climate change.¹⁵ These benefits include reduced climate variability and a reduced probability of environmental disaster. Importantly, the benefits from mitigation are shared equally by all countries (ECUs in the mitigation account are divided equally amongst the 5 group members), irrespective of individual investment in mitigation.

Assuming that the target (threshold) is not met

If a group fails to meet the abatement target, in terms of the framing, there is a temperature warming of above 2° Celsius. In this case, as countries do not experience the benefits of mitigation, such as reduced climate variability, there is no return from investing in the mitigation account: $\alpha_i = 0$.

Furthermore, as explained to participants, each player is obliged to use a portion of the funds in his or her private account for investment in adaptation and to fund disaster relief. As such, if the emission reduction target is not met, each player loses a portion of the ECUs in his/her private account ($1-\lambda_i$). Developing countries, which are likely to be affected the most severely

¹³ $177 \text{ MtCO}_2 - 115 \text{ MtCO}_2 = 62 \text{ MtCO}_2$.

¹⁴ $77 \text{ ECUs multiplied by the emission factor of } 1.5 = 115.5 \text{ MtCO}_2$.

¹⁵ Barrett and Dannenberg (2012) make the distinction between scientific thresholds and political targets. Within the context of the game, we have a specific provision point (threshold) of 77 ECUs. This provision point conveys the scientific threshold of a 2° Celsius increase in mean global temperature (the threshold for dangerous warming). Within the context of the game, if at least 77 ECUs are contributed to the public good, the provision point has been met and a temperature increase of above 2° Celsius has been avoided. In terms of the political target, policymakers have pledged to collectively reduce emissions by 115MtCO₂ in order to meet this scientific threshold. As evident from footnote 14, this is the collective mitigation needed to ensure that the threshold is met (i.e. that 77 ECUs are contributed to the public good). Thus while a political target of reducing emissions by 115MtCO₂ has been decided, it is up to the individual players to decide how to distribute this abatement burden.

by climate change, will need more severe adaptation and disaster relief measures. As such, developing-country players lose a larger share of the ECUs in their private account. Specifically: $\lambda_i = 0.75$ for the US and EU and $\lambda_i = 0.50$ for China, India and SA (equation 2). In other words, if the threshold is not met, developed-country players lose 25% of the ECUs in their private account, while developing-country players lose 50%.

4.3 Treatments

In the *first treatment* (which will be referred to as “ON” for own nationality), participants represent their own country (for example an American player uses the US payoff function) and must select one of four equity principles, each one synonymous with a different ECU-value contribution to mitigation. The four burden-sharing principles, adapted from Lange *et al.* (2007, 2010) are as follows:

- (1) **Equal per capita entitlement to emissions (egalitarian principle) (EPC):** If the population of your country represents x% of the global population, you are entitled to x% of global emissions entitlements.
- (2) **Equal percentage reduction of current emissions (sovereignty rule) (EPR):** If your country’s current emissions amount to x% of global emissions, you should get x% of global emissions entitlements.
- (3) **Historical polluter-pays rule (HPP):** The abatement burden is allocated according to *historical* responsibility (1980 – 2000). If your country’s emissions between 1980 and 2000 amount to x% of global emissions in that time, you are responsible for x% of the reduction target.
- (4) **Future polluter-pays rule (FPP):** The abatement burden is allocated according to *future* responsibility (2010 – 2030). If your country’s projected emissions between 2010 and 2030 will amount to x% of projected global emissions in that time, you are responsible for x% of the reduction target.

Each equity principle translates into different ECU obligations (and therefore income) for each country. Table 4 (a version of which was shown to the participants) illustrates the ECU contributions associated with each equity principle, for each region. The egalitarian (equal per capita emissions) and historical polluter-pays rules shift the majority of the abatement responsibility to developed countries who have high per capita emissions and historical responsibility for emissions (Cazorla and Toman 2000). As is evident from table 4, these equity principles prescribe the largest ECU contributions for the US and EU and the smallest contributions for China and India, relative to the other equity principles. Conversely, the future polluter-pays rule renders large emerging economies such as China and India more responsible for mitigation, relative to the other equity principles. This burden-sharing principle translates into the largest ECU contribution for China and India (relative to the other equity principles). Finally, the sovereignty rule (equal percentage reduction of current emissions) ensures that relative emission levels between countries remain unchanged. This principle is favourable for the US and EU relative to the historical polluter-pays rule and egalitarian rule.

SA's public good contributions do not vary significantly across the different equity principles, ranging between 1 and 2 ECUs (table 4). However, given South Africa's status as the largest emitter in Africa and the country's participation in on-going climate negotiations (for example, its role along with the other BASIC countries and the US in brokering the Copenhagen Accord), the region was included in the study.

As illustrated in table 4, the cost ranking of equity principles (in terms of ECU contributions to the public good) for each region is as follows:

- (1) United States: $EPC > HPP > EPR > FPP$
- (2) European Union: $HPP > EPC > EPR > FPP$
- (3) China: $FPP > EPR > EPC > HPP$
- (4) India: $FPP > EPR > HPP > EPC$
- (5) South Africa $HPP/FPP > EPC/EPR$

Table 4. ECU contribution to the mitigation account and payoff, by burden-sharing principle

<i>Panel A: equal per capita emissions (EPC)</i>						
	% of population	Share of group entitlement ^a	ECU endowment	Current emissions ^b	Emissions in 2050	ECU contribution
US	0.09	6	70	58	6	35
EU	0.15	9	70	41	9	21
China	0.40	25	50	62	25	25
India	0.34	21	25	13	21	0
SA	0.01	1	15	3	1	1
<i>Panel B: equal percentage reduction of current emissions (EPR)</i>						
	Current emissions ^b	Share of current emissions ^b	Share of entitlement ^a	ECU endowment	Emissions in 2050	ECU contribution
US	58	0.33	20	70	20	25
EU	41	0.23	14	70	14	18
China	62	0.35	22	50	22	27
India	13	0.07	4	25	4	6
SA	3	0.02	1	15	1	1
<i>Panel C: historical polluter-pays (HPP)</i>						
	% of emissions 1980-2000	Share of burden ^c	Current emissions ^b	ECU endowment	Emissions in 2050	ECU contribution
US	0.40	46	58	70	12	31
EU	0.33	38	41	70	3	25
China	0.20	23	62	50	39	15
India	0.05	6	13	25	7	4
SA	0.02	2	3	15	1	2
<i>Panel D: future polluter-pays (FPP)</i>						
	% of emissions 2010-2030	Share of burden ^c	Current emissions ^b	ECU endowment	Emissions in 2050	ECU contribution
US	0.26	30.0	58	70	28	20
EU	0.18	20.3	41	70	21	14
China	0.44	50.6	62	50	11	34
India	0.10	11.7	13	25	1	8
SA	0.02	2.3	3	15	1	2

Notes:

^a The group is entitled to emit 62 MtCO₂

^b Using 2006 data for current emissions from table 3

^c The groups' emission reduction burden is to reduce emissions by 115MtCO₂

The table illustrates that if all participants select the same burden-sharing principle, the cumulative contribution of the group is sufficient to meet the threshold.

The *second treatment* (which will be referred to as “RN” for random nationality) is identical to the first with the exception that participants no longer represent the country of which they are a national, but are randomly allocated to a region once they have selected a burden-sharing rule.

Subjects also participated in two additional treatments (described in the footnote) which are not discussed here.¹⁶

4.4 Equilibria and best responses

The experiment reported here is an n-person threshold public good game where each player has four possible actions. Because of the structure of the game, where equity principles denote varying contributions to the public good for the respective regions, all equilibria are asymmetric in terms of participants contributing different amounts (of ECUs) to the public good. As the large number of equilibria makes classification difficult, we provide a number of examples of pure strategy Nash equilibria in table 5.

The game has an inefficient pure strategy equilibrium whereby all players contribute the minimum permissible amount to the public good (as evident from table 4, it is not possible for players to contribute zero); in this case, group contributions are not sufficient to meet the threshold. As illustrated in table 5, the inefficient low-contribution equilibrium is reached when players select the following equity principles: (i) US: future polluter-pays, (ii) EU: future polluter-pays, (iii) China: historical polluter-pays, (iv) India: equal per capita emissions and (v) SA: equal per capita emissions or equal percentage reduction of current emissions.

Additionally, all combinations of equity principles that result in the group reaching the threshold of 77 ECUs, irrespective of individual contribution levels, are Nash equilibria; the caveat is that a player must *not* be able to reduce their contribution level without cumulative group contributions decreasing below the threshold.¹⁷ Table 5 provides two further examples of combinations of equity principles that are Nash equilibria (we call these mixture strategies as the choice of equity principle is varied as opposed to being symmetric).

¹⁶ In the two additional treatments, which subjects were presented with first, participants don't use burden-sharing principles, but rather specify how many ECUs they would like to contribute to mitigation (the public account). As with the treatments utilizing equity principles, subjects initially act as representative for the country of which they are a national while, in the subsequent treatment, they are randomly assigned to one of the countries in the game after making their decision.

¹⁷ For example, a symmetric strategy whereby all players opt for the principle of equal per capita emissions results in a cumulative group contribution (82 ECUs) that exceeds the threshold (77 ECUs). This strategy is not a NE as the best response of the US player, given that all other players select equal per capita emissions, is to choose the historical polluter-pays principle. This results in a cumulative group contribution of 78 ECUs (still reaching the threshold).

Table 5. Equity principle combinations that are pure strategy Nash equilibria (corresponding ECU contribution in parenthesis) [corresponding total payoff for each region in square brackets]

Pure strategy NE	US	EU	China	India	SA
Low-contr. strategy	FPP (20) [38]	FPP (14) [42]	HPP (15) [18]	EPC (0) [13]	EPC/EPR (1) [7]
Mixture strategy example 1:	EPR (25) [68]	EPC (21) [72]	EPC (25) [48]	EPR (6) [42]	EPC/EPR (1) [37]
Mixture strategy example 2:	EPC (35) [58]	EPR (18) [75]	HPP (15) [58]	FPP (8) [40]	EPC (1) [37]

Notes:

- Abbreviations: EPC: equal per capita entitlement to emissions, EPR: equal percentage reduction of current emissions, HPP: historical polluter-pays and FPP: future polluter-pays.
- Players can also have symmetric strategies in terms of all selecting the same equity principle. In this case symmetric strategies of HPP or EPR are Nash equilibria while symmetric strategies of EPC and FPP are not (footnote 17).

More generally, the figures in Appendix C illustrate the individual best responses for each region (in the *ON* treatment this is also the best response for each nationality) given the cumulative contributions of the *remaining* group members. Given the large set of possible combinations of equity principles (and resultant cumulative group contributions), we provide only an example of possible contribution levels, spanning from minimum to maximum permissible contribution levels. An example of the combination of equity principles associated with each contribution level is provided in text boxes just below the horizontal axis.

An interpretation of figure C1 for the US (and the American player in the *ON* treatment) is provided: if cumulative contributions of the remaining group members sum to below 42 ECUs, even the maximum US contribution of 35 ECUs (for the principle of equal per capita entitlement to emissions) is insufficient to push the group to the threshold. In this case, the best response for the US player is to contribute as little as possible to the public good by selecting the future polluter-pays principle. Thereafter, it is in the best interest of the US player to contribute the minimum permissible amount needed to reach the threshold. For example, if the remaining group members collectively contribute 50 ECUs to public good provision, the best response for the US is to select the historical polluter-pays principle (synonymous with a contribution of 31 ECUs to the public good). Once the others contribute a minimum of 57 ECUs, the US player's best response reverts back to selecting the future polluter-pays principle (as this is the lowest permissible contribution level for the US region).

4.5 Procedures

The experiment was conducted as an online survey. Specifically, participants, who signalled interest by emailing one of the authors, were provided with the web address of the survey and a unique password. Anyone experiencing difficulty in accessing the online survey (mainly in Asia) was sent a word-document version.

Once participants submitted their decisions, they were randomly assigned to groups and their payoffs were calculated (note: students were grouped with students; the same for practitioners). Participants were aware that their group consisted of players from the other countries represented in the experiment. Participants were also aware of each country's endowment, payoff function and payoff tables. Participants were not aware that the sample consisted of practitioners and students.

At the start of each treatment, participants were re-allocated their endowment. They remained in the same group for the duration of the experiment.

The experiment referred to ECUs (experimental currency units). An exchange rate for the conversion of ECUs into US Dollars was specified in the introduction.¹⁸ In addition, students were provided with a \$5 participation fee and practitioners a \$15 participation fee. Each subject's total dollar earnings were converted into their local currency using Purchasing Power Parity conversion rates from the International Monetary Fund (IMF) April 2010 World Economic Outlook (WEO) database (WEO 2010).

With the exception of South Africans who were paid with cash cheques (students) and electronic bank transfers (practitioners), participants were paid via PayPal.

In the treatments where participants are randomly assigned to a country, American, European, Chinese, Indian and South African participants were randomly assigned to SA, India, the US, China and the EU, respectively.

¹⁸ 1 ECU = \$0.2 in the student sample; 1 ECU = \$0.6 in the practitioner sample.

After all the treatments were concluded, the participants also completed a short survey that captured their demographic information and attitudes to climate change and burden-sharing principles.

5 Results

Across all treatments and including the participation fee, average dollar earnings (before conversion into PPP rates) for American, European, Chinese, Indian and South African students are \$38, \$43, \$46, \$36 and \$39, respectively. Comparable earnings for American, European, Chinese, Indian and South African practitioners are \$117, \$116, \$133, \$102 and \$115, respectively.

The primary focus of the experiment reported here is to examine the extent to which individuals' use of equity principles reflects self-interest and to consider the impact of self-interest on the negotiating process. Ultimately, we examine how equity principles shift across the two treatments, when players move from a known to unknown payoff function. This allows us to examine how preferences for equity principles shift when all considerations other than fairness are stripped away.

As previously mentioned, in terms of the design, as the financial cost associated with each equity principle differs among regions, self-interested use of equity principles necessitates that different regions support different equity principles to different degrees (Lange et al. 2010). Based on the findings by Lange *et al.* (2010) and Carlsson *et al.* (2013), which are compatible with self-interested use of equity principles, as well as the broader empirical findings in line with a self-serving bias (Babcock, Wang and Loewenstein 1996, Babcock and Loewenstein 1997, Babcock *et al.* 1997, Brekke and Johansson-Stenman 2008), we expect self-interest in this game to manifest in the *ON* (own nationality) treatment as each player choosing the equity principle that is most likely to maximise his payoff. In the case of both US and EU players, the future polluter-pays and equal percentage reduction principles are generally most profitable, given the contributions of others, while, selecting the principles of historical polluter-pays and equal per capita emissions is generally in the best interests of China and India (figures in Appendix C). The case for the South African player differs in that the player's payoff varies very little across equity principles (figure C5 in Appendix C). The expectation is that South

African players' choices should thus solely reflect fairness and therefore vary little between the *ON* and *RN* treatments.¹⁹

5.1 Experimental results

In the *ON* (own nationality) and *RN* (random nationality) treatments, participants choose between four burden-sharing principles that determine their contribution to mitigation. In *ON*, subjects represent the country of which they are a national, while in *RN*, subjects are randomly allocated to a region.

Table 6 reflects the percentage with which each principle was selected in both treatments (*ON* and *RN*) for the pooled sample (this information is replicated graphically in figure 1). Results for the student and practitioner subsamples are provided in Appendix D.

American participants:

In the *ON* treatment (where players represent the country of which they are a national), the majority of US players (64%) select either the future polluter-pays rule (26%) or the principle of equal percentage reduction (38%). These equity principles denote the smallest ECU contribution to public good provision for the US (table 4) and are the principles most synonymous with material self-interest in the case of the US (Figure C1, Appendix C). With respect to the on-going climate negotiations, Saran (2010) notes the refusal of the US to accept binding mitigation obligations without a reciprocal obligation from large emerging economies. In this context, the large proportion of US players favouring the future polluter-pays and equal percentage reduction rules is consistent with this preference for emerging economies to participate in emission reduction efforts.

¹⁹ The figures in Appendix C show that the return for a particular country is always higher when the threshold is met. More specifically, the worst outcome for a given country when the threshold is met is superior to the best outcome when the threshold is not met. The implication is that players' decisions are likely to be influenced by their expectations of the likelihood of the threshold being met coupled with their risk attitudes (Tavoni et al. 2011). In addition, social preferences – and in particular inequity aversion – might further influence players' choices (Fehr and Schmidt 1999, Dannenberg et al. 2007). For an example of how risk aversion and inequity aversion can manifest in the game, consider an American player who is pessimistic about the threshold being met in the *ON* treatment. While opting for the future polluter-pays principle would ensure the highest return, the individual might rather select the equal percentage reduction rule to improve the outcome for other players. However, against this background, while risk attitudes and social preferences are likely to account for heterogeneity of preferences at the individual level, this article considers behaviour pooled across nationalities and, in particular, how preferences for equity principles among different nationalities shift across the two treatments.

Conversely, in the *RN* treatment, where players are to be randomly assigned to a region irrespective of their own nationality, 62% of American players select either the historical polluter-pays rule (28%) or the principle of equal per capita entitlement to emissions (34%), the principles usually advocated by developing countries. It appears that American players are following a maximin strategy, assuring themselves of the highest possible payoff in the advent of being allocated to either China or India.

More specifically, in the *RN* treatment, the proportion of American players favouring the principle of equal percentage reduction of current emissions declined significantly to 23% (McNemar Chi-square test: $p = 0.025$), while the proportion favouring the future polluter-pays rule decreased to 15% (significant at the 10% level) (McNemar Chi-square test: $p = 0.090$). In addition, the proportion opting for the historical polluter-pays rule, the second most expensive principle in terms of contributions to mitigation, increased significantly from 12% in *ON* to 28% in *RN* (McNemar Chi-square test: $p = 0.008$).

European participants:

In the *ON* treatment, despite the future polluter-pays and equal percentage reduction rules generally being the best response for European players, the majority of European players (61%) select the principles of historical polluter-pays (26%) and equal per capita entitlement to emissions (35%), the principles requiring the largest contributions to mitigation for the EU and that are generally synonymous with the lowest payoff for the region. More so, the distribution of choices by European players does not change significantly in the *RN* treatment (McNemar Chi-square tests: $p > 0.05$ for all equity principles), with 62% of players selecting the same principles. Overall, this result is not in line with self-interested use of burden-sharing principles by European participants.

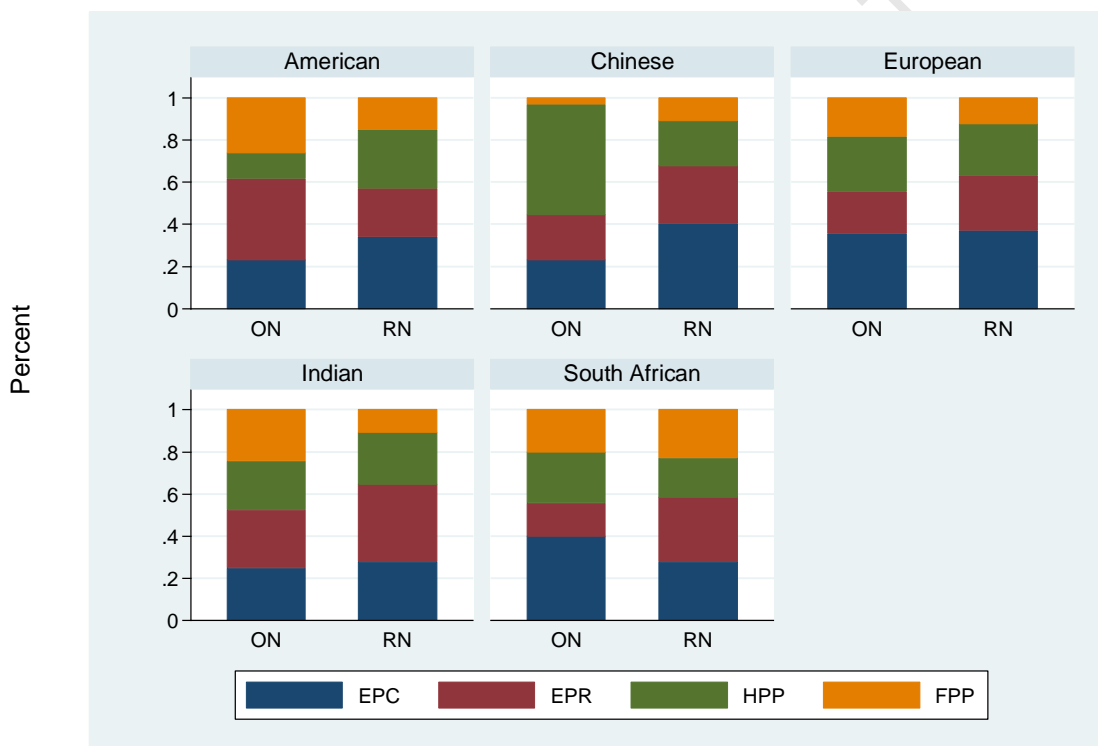
Table 6. Burden sharing principles, by nationality

Burden-sharing principle	Participant nationality:									
	American		European		Chinese		Indian		South African	
	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>
Equal per capita	0.23	0.34	0.35	0.37	0.23	0.40	0.25	0.28	0.40	0.28
Equal % reduction	0.38	0.23	0.20	0.26	0.22	0.28	0.28	0.37	0.15	0.31
Historical polluter-pays	0.12	0.28	0.26	0.25	0.52	0.22	0.23	0.25	0.25	0.18
Future polluter-pays	0.26	0.15	0.18	0.12	0.03	0.11	0.25	0.11	0.20	0.23

Notes:

- *ON*: own nationality; *RN*: Random nationality;
- $N = 325$ (merged sample of students and practitioners)
- $n = 65$ (representatives of each nationality).

Figure 1. Burden sharing principles, by nationality, for *ON* and *RN*



Notes:

- *ON*: own nationality; *RN*: Random nationality.

Chinese participants:

In the *ON* treatment, 75% of Chinese participants opt for the principle of historical polluter-pays (52%) and equal per capita emissions (23%), the principles most compatible with material self-interest for China. Conversely, in *RN*, when participants are to be randomly allocated to a region, the proportion of Chinese participants favouring the historical polluter-pays rule decreases significantly by more than half to 22% (McNemar Chi-square test: $p = 0.000$), while the proportion choosing the principle of equal per capita emissions increases significantly to 40% (McNemar Chi-square test: $p = 0.028$). While the proportion favouring the future polluter-pays rule increases from 3% to 11%, this increase is only significant at the 10% level (McNemar Chi-square test: $p = 0.096$).

With 62% of participants in the *RN* treatment still favouring the principle of equal per capita emissions and the historical polluter-pays rule, it also appears as if Chinese players are following a maximin strategy, assuring themselves of the highest possible payoff in the advent of being allocated to either China or India. However, the redistribution of preferences from the principle of historical polluter-pays to the rule of equal per capita emissions, which prescribes a larger contribution to the public good of 25 ECUs as opposed to 15 ECUs for the historical polluter-pays rule and which is generally the second most profitable strategy (figure C3, Appendix C), might signal that the principle of equal per capita emissions is genuinely considered to be the more “fair” of the two strategies.

Indian participants:

The choices of Indian participants are distributed roughly equally amongst the four principles in the *ON* treatment (equal per capita emissions: 25%, equal percentage reduction of emissions: 28%, historical polluter-pays: 23%, future polluter-pays: 25%).

In *RN*, the proportion of participants selecting the future polluter-pays rule decreases significantly to 11% (McNemar Chi-square test: $p = 0.029$), while the proportion favouring equal percentage reduction of current emissions increases to 37% (although this increase is not significant; McNemar Chi-square test: $p = 0.157$). The fact that the number of participants selecting the future-polluter-pays rule more than halves in *RN* is surprising. A possible explanation is that while a quarter of Indian participants think it genuinely fair that India be held accountable now for their future emissions, the desirability of this principle declines when

the participants are unsure as to which country/region they will be representing (for example the EU or SA).

South African participants:

In *ON*, the majority of South African participants (65%) favour the principles of equal per capita entitlement to emissions (40%) and historical polluter-pays (25%). In *RN*, the proportion selecting the principle of equal percentage reduction of current emissions doubles to 31% (McNemar Chi-square test: $p = 0.004$), while the proportion selecting the principle of equal per capita entitlement to emissions decreases to 28% although this decrease is only significant at the 10% level (McNemar Chi-square test: $p = 0.059$).

5.2 Regression analysis

The relationship between nationality and choice of burden-sharing principle is further assessed using logistic regression analysis, the results of which are replicated in table 7. The dependent variables, *historical polluter-pays* (columns 1 and 2) and *future polluter-pays* (columns 3 and 4), take on a value of 1 if subjects selected these principles. Explanatory variables incorporated into the model include: *Practitioner* (equals 1 if a participant is a practitioner as opposed to a student), dummy variables for nationality and gender and, finally, age in years. While the regression coefficients are reported in table 7, the marginal effects are provided in Appendix E.

In columns 1 and 2 (dependent variable: historical polluter-pays), the reference nationality is *American*. The results for *ON* (own nationality) in column 1 indicate that practitioners are more likely to select the principle of historical polluter-pays relative to students (0.7999, $p = 0.042$). In addition, European, Chinese, Indian and South African participants are more likely to select the historical polluter-pays principle relative to their American counterparts (for Indian participants, the effect is only significant at the 10% level) (European: 1.044, $p = 0.037$; Chinese: 2.251, $p = 0.000$; Indian: 0.910, $p = 0.069$, South African: 0.978, $p = 0.048$). In *RN*, when subjects no longer represent their own regions and are randomly allocated to a country, these effects are no longer significant (column 2).

In columns 3 and 4 of table 7 (dependent variable: future polluter-pays), the reference nationality is *Chinese*. The results for *ON* (own nationality) in column 3 indicate that all nationalities are more likely to select the principle of future polluter-pays relative to Chinese participants (Americans: 2.719, $p = 0.001$; Europeans: 1.842, $p = 0.020$; Indians: 2.293, $p = 0.003$; South Africans: 1.860, $p = 0.019$). In *RN*, when subjects are randomly allocated to a country, these effects disappear for American, European and Indian participants (column 4) (Americans: 0.359, $p = 0.515$; Europeans: 0.233, $p = 0.680$; Indians: 0.017, $p = 0.977$; South Africans: 1.065, $p = 0.046$). In addition, in *RN*, practitioners are significantly less likely to select the future polluter-pays principle as compared to students (-2.092 , $p = 0.019$).

Table 7. Logistic regressions, historical and future polluter-pays principles

	(1)	(2)	(3)	(4)
	Historical polluter-pays <i>Reference nationality:</i> <i>American</i>		Future polluter-pays <i>Reference nationality:</i> <i>Chinese</i>	
	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>
Practitioner	0.799* (0.392)	0.428 (0.396)	-0.617 (0.576)	-2.092* (0.893)
American	-	-	2.719** (0.795)	0.359 (0.551)
European	1.044* (0.499)	-0.108 (0.416)	1.842* (0.790)	0.233 (0.566)
Chinese	2.251** (0.487)	-0.300 (0.423)	-	-
Indian	0.910 (0.501)	-0.111 (0.427)	2.293** (0.782)	0.017 (0.580)
South African	0.978* (0.494)	-0.479 (0.438)	1.860* (0.792)	1.065* (0.534)
Age	0.028 (0.029)	0.011 (0.026)	-0.073 (0.062)	0.010 (0.055)
Female	-0.133 (0.272)	-0.000 (0.278)	-0.506 (0.322)	0.321 (0.336)
Constant	-2.921** (0.875)	-1.382 (0.752)	-1.347 (1.565)	-2.324 (1.402)

Note: Robust standard errors in parentheses; * and ** indicate significance at the 5% and 1% level, respectively; standard errors adjusted for clustering; results reported as coefficients

Table 8 reflects the results of ordinal random effects panel regressions for each nationality, aimed at determining how the correlation between cost rankings of equity principles and participants' preferences differ between the *RN* and *ON* treatments. From the discussion of the experimental results in subsection 5.1, it is expected that American and Chinese participants

are more likely to opt for equity principles that prescribe larger public good contributions in *RN* relative to *ON*.

The dependent variable is a region-specific four level variable, that ranks the equity principles (for each region) according to cost (in terms of contribution to the public good). In addition to the explanatory variables for *Age* and *Female* included in the previous regressions, a dummy variable for treatment is incorporated into the model (where the *RN* treatment equals 1). As expected, the results indicate that, in the *RN* (random nationality) treatment, both American and Chinese participants are more likely to choose equity principles with a higher cost ranking (that prescribe larger contributions to the public good) relative to the *ON* treatment (American: 0.927, $p = 0.007$; Chinese: 1.254, $p = 0.000$).

Table 8. Ordinal random effects panel regressions examining the relationship between equity preferences and cost rankings

	(1)	(2)	(3)	(4)	(5)
	American	European	Chinese	Indian	South African
Practitioner	0.725 (0.652)	0.441 (0.588)	-0.729 (0.808)	0.190 (0.521)	1.043 (1.811)
<i>RN</i>	0.927** (0.343)	0.045 (0.338)	1.254** (0.335)	-0.436 (0.332)	-0.223 (0.478)
Age	-0.037 (0.033)	0.111 (0.059)	-0.036 (0.049)	-0.108 (0.062)	-0.043 (0.131)
Female	-0.015 (0.488)	0.546 (0.384)	0.923* (0.429)	-0.692 (0.430)	-1.109 (0.888)
Observations	130	128	130	130	130

Note: Robust standard errors in parentheses; * and ** indicate significance at the 5% and 1% level, respectively; standard errors adjusted for clustering

5.3 Meeting the target

In *ON* (own nationality), approximately 37% of groups met the target. This proportion increased significantly to 57% in *RN* when participants were to be allocated a nationality at random (McNemar Chi-square test: $p = 0.016$).

As previously mentioned, in the *RN* treatment, where participants are randomly assigned to a region: (i) Chinese participants were assigned to the US and (ii) Indian participants were assigned to China.

In this context, table 9 compares: (i) the average ECU contributions for the US region in the ON treatment (contributions by Americans) relative to the RN treatment (contributions determined by the equity preferences of Chinese participants); and, (ii), the average ECU contributions for the China region in the ON treatment (contributions by Chinese participants) versus the RN treatment (contributions determined by the equity preferences of Indian participants).

The increase in the proportion of groups meeting the target in RN is due to an increase in average contributions for the US and China regions in RN relative to ON. Specifically, average contributions for the US region increased from 26.5 in ON to 30 in RN; additionally, average contributions for the China region increased from 20.5 in ON to 24.5 in RN.

Table 9. Average contributions to the public good for the US and China in *ON* and *RN* treatments

Region:	Nationality (Treatment)	
US	American (ON)	Chinese (RN)
	26.5	30
China	Chinese (ON)	Indian (RN)
	20.5	24.5

The increase in average contributions for the US region in *RN* (30) relative to *ON* (26.5) is due to the fact that, in *ON*, 64% of American participants opted for the principles of future polluter-pays and equal percentage reduction of current emissions, both of which are synonymous with the smallest public good contribution; conversely, in *RN*, 62% of Chinese participants selected the principles of equal per capita entitlement to emissions and historical polluter-pays, the equity principles that denote the largest contributions for the US region.

With respect to the China region, in *ON*, 52% of Chinese participants opt for the historical polluter-pays rule, which denotes the smallest public good contribution for China, while, in *RN*, the proportion of Indian participants selecting this principle is considerably less at 25%. In addition, while 22% and 3% of Chinese participants select the principles of equal percentage reduction of emissions and future polluter-pays, respectively (the principles commensurate with the largest ECU contribution for China), in *RN*, the proportion of Indian participants opting for this principle is considerably higher at 37% and 11%, respectively.

6 Discussion

Despite global consensus on the science behind climate change, the inability to negotiate a post-2012 climate agreement, coupled with the decision of Russia, Canada, Japan and the US to reject the second commitment period of the Kyoto Protocol, has created an atmosphere of pessimism around the success of future climate negotiations (Andonova and Alexieva 2012, Weiler 2012, Gupta 2012).

Through the Durban Platform for Enhanced Action, negotiations are underway on a new global climate agreement, to be completed by the end of 2015 and enter into force in 2020. This new treaty would need to amalgamate into a single regime the mixed bag of binding and non-binding arrangements currently existing under the United Nations Climate Convention (European Commission 2013).

Signalling the importance of burden-sharing principles in climate negotiations, government officials from the BASIC countries have emphasised that a “global goal for emission reductions should be preceded by the definition of a paradigm for equitable burden sharing’ (Winkler *et al.* 2011). Within this context, this study considers just one of the negotiating challenges prevalent in multilateral climate negotiations: namely, the potential for self-interested use of equity principles. For example, where negotiators advocate certain burden-sharing principles to legitimise their negotiating position rather than out of a genuine sense of fairness. In this context, this study considers a small selection of the burden-sharing principles prevalent in both the literature and the negotiations: specifically, the principle of equal percentage reduction of current emissions, the principle of equal per capita entitlement to emissions and two variants of the polluter-pays rule, namely, historical and future polluter-pays.

In this context, the experiment reported here examines the extent to which individuals’ use of equity principles reflects material self-interest (in other words, whether individuals use equity principles in a self-serving way). To do so, we use a threshold public good game with a climate change framing, where groups of individuals, consisting of participants from the US, EU, China, India and SA, must collectively meet an emission reduction target. In the first treatment, called the own nationality treatment, the participants choose between various equity principles

when the cost ranking (in terms of contributions to the public good) of each principle is made explicit for each of their respective nationalities.

In line with the findings of Lange *et al.* (2010) and Carlsson *et al.* (2013), choice of equity principle among American and Chinese players is found to be in line with material self-interest. Specifically, in the own nationality treatment (where players represent the country of which they are a national), the majority of US players (64%) select either the future polluter-pays rule (26%) or the principle of equal percentage reduction of current emissions (38%). These equity principles denote the smallest contribution to public good provision and are the principles most synonymous with material self-interest. Lange *et al.* (2010) find that the US is primarily perceived as supporting the principle of equal percentage reduction of current emissions. These findings are consistent with the refusal by the US to ratify the Kyoto Protocol without large emerging economies accepting reciprocal mitigation obligations (Saran 2010).

With respect to Chinese participants, in the own nationality treatment, 75% of Chinese participants select either the principle of equal per capita emissions or the historical polluter-pays rule. This reflects the BASIC countries' emphasis on equity and historical responsibility in the context of distributing an abatement burden (Winkler *et al.* 2011).

This result, that choice of burden-sharing principle is (at least partly) derived from material self-interest, is important in the context of multilateral climate negotiations where the equity principle that an agent adheres to will likely affect or shape the negotiating process (and by extension, the negotiation outcome). Against this background, this experiment further examines the impact of self-interest on the negotiating process. To do so, in a second treatment, while participants must once again choose between the various burden-sharing principles, they do so from behind a veil of ignorance, where they no longer know which payoff function is applicable to them. This allows us to examine how preferences for equity principles shift when all considerations other than fairness are stripped away.

The results indicate that both American and Chinese participants are more likely to opt for equity principles with a higher cost ranking in the random nationality treatment. More specifically, in the own nationality treatment, when representing America, the odds of selecting the principle of historical polluter-pays are lower for American participants relative to other nationalities – however, this effect all but disappears in the random nationality treatment.

Furthermore, in the random nationality treatment, 62% of American players select either the historical polluter-pays rule (28%) or the principle of equal per capital entitlement to emissions (34%), the principles usually advocated by developing countries. It appears that American players are following a maximin strategy, assuring themselves of the highest possible payoff in the advent of being allocated to either China or India.

Chinese participants are less likely to select the principle of future polluter-pays in the own nationality treatment relative to other nationalities, an effect that disappears in the random nationality treatment. Furthermore, in the random nationality treatment, the proportion of Chinese participants selecting the principle of historical polluter-pays decreases significantly from 52% to 22%, while the proportion selecting the principle of equal per capita emissions, which requires a larger ECU contribution to mitigation, increases significantly from 23% to 40%.

In contrast to the findings for American and Chinese participants, the results for European players are not consistent with material self-interest. Specifically, in the own nationality treatment, despite the principles of future polluter-pays and equal percentage reduction of current emissions generally being the best response for European players, the majority (61%) opt for the principles of historical polluter-pays (26%) and equal per capita entitlement to emissions (35%), the principles requiring the largest contributions to mitigation for the EU and that are generally synonymous with the lowest payoff for the region. More so, the distribution of choices by European players does not change significantly across the two treatments.

The discussion above illustrates that the preferences for equity principles by American and Chinese participants shifted in the random nationality treatment, where considerations other than fairness were stripped away. Furthermore, the results signal that the self-interested use of equity principles impedes success in meeting the specified threshold (in terms of the framing: the emission reduction target). Specifically, in the own nationality treatment, approximately 37% of groups met the target; this proportion increased significantly to almost 57% in the random nationality treatment. The greater success in meeting the target in the random nationality treatment was due to an increase in average contributions for the US and China regions in the random nationality treatment. Specifically, while the majority of American and Chinese participants selected equity principles that minimised their contributions to the public

good in the own nationality treatment, the equity preferences in the subsequent random nationality treatment meant contributions for both regions were increased. This result signals that self-interested use of equity principles manifests in lower public good contributions.

Within the context of ongoing climate policy, Barrett and Dannenberg (2012) note that, despite there being consensus around the 2 degree scientific threshold for dangerous climate change, the voluntary emission reduction pledges under the Copenhagen Accord (a pledge and review system of voluntary emission reduction targets) virtually guarantee that the target of keeping temperature warming to below 2 °C will be missed. While Barrett and Dannenberg show that threshold uncertainty impedes the negotiation process, the results of this article indicate that self-interested use of equity principles might additionally explain the gap between the voluntary pledges and scientific threshold: specifically, negotiators are able to make pledges that are more in line with their own material self-interest (and that collectively are insufficient to meet the threshold) while still legitimising their position through the use of equity principles. Tavoni *et al.* (2011) consider the impact of nonbinding pledges on success in meeting a threshold in a threshold public good game. The authors draw parallels with the nonbinding pledge and review system of the Copenhagen Accord. The authors find nonbinding pledges (acting as signals of commitment) to be an effective way to communicate intentions – with success in meeting the threshold increasing significantly with the introduction of the nonbinding announcements. Tavoni *et al.* argue that success in climate negotiations is predicated on wealthier countries accepting a larger share of the abatement burden and signalling this intent early on. In this context, the current pledge and review architecture is an avenue for regions with less of a self-serving bias (European and Indian players within the context of the game) to facilitate coordination by signalling their intent early on.

References

- Anderson, C., Putterman, L. 2006. Do non-strategic sanctions obey the law of demand? The demand for punishment in the voluntary contribution mechanism. *Games and Economic Behaviour* 54:1 – 24.
- Babcock, L., Wang, X., Loewenstein, G. 1996. Choosing the Wrong Pond: Social Comparisons in Negotiations that Reflect a Self-Serving Bias. *The Quarterly Journal of Economics* 111(1): 1-19.
- Babcock, L., Loewenstein, G. 1997. Explaining Bargaining Impasse: The Role of Self-Serving Biases. *The Journal of Economic Perspectives* 11(1): 109-126.
- Babcock, L., Loewenstein, G., Issacharoff, S., Camerer, C. 1997. Biased Judgments of Fairness in Bargaining. *The American Economic Review* 85(5): 1337-1343.
- Barrett, S. 2013. Climate Treaties and Approaching Catastrophes. *Journal of Environmental Economics and Management*.
- Barrett, S., Dannenberg, A. 2012. Climate Negotiations under Scientific Uncertainty. *PNAS Early Edition*.
- Brekke, K., Johansson-Stenman, O. 2008. The behavioural economics of climate change. *Oxford Review of Economic Policy* 24(2):280 – 297.
- Burnham, T., McCabe, K., Smith, V. 2000. Friend-or-For? Intentionality Priming in an Extensive Form Trust Game. *Journal of Economic Behavior & Organization*, 43: 57-73.
- Climate Analysis Indicators Tool (CAIT). 2010. Version 7.0, Washington, DC, World Resources Institute.

- Carlsson, F., Kataria, M., Krupnick, A., Lampi, E., Lofgen, A., Qin, P., Sterner, T. 2013. A fair share: Burden-sharing preferences in the United States and China. *Resource and Energy Economics* 35: 1 – 7.
- Cazorla, M., Toman, M. 2000. International Equity and Climate Change Policy. Resources for the Future, Climate Issue Brief No. 27.
- Croson, R., Marks, M. 1998. Identifiability of Individual Contributions in a Threshold Public Goods Experiment. *Journal of Mathematical Psychology* 42: 167-190.
- Dannenberg, A., Sturm, B., Vogt, C. 2010. Do Equity Preferences Matter for Climate Negotiators? An Experimental Investigation. *Environ Resource Econ* 47: 91 – 109.
- Dannenberg, A., Löschel, A., Paolacci, G., Reif, C., Tavoni, A. 2011. Coordination under Threshold Uncertainty in a Public Goods Game. Centre for Climate Change Economics and Policy Working Paper No. 74, Grantham Research Institute on Climate Change and the Environment Working Paper No. 64.
- Eckel, C., Grossman, P. 1996. Altruism in Anonymous Dictator Games. *Game and Economic Behavior*, 16: 181-191.
- Fehr, E., Fischbacher, E., 2004. Social norms and human cooperation. *Trends in Cognitive Sciences* 8(4):185 – 190.
- Fehr, E., Gächter, S. 2000. Cooperation and Punishment in Public Goods Experiments. *The American Economic Review* 90(4):980 – 994.
- Fehr, E., Gächter, S. 2002. Altruistic punishment in humans. *Nature* 415:137 – 140.
- Fischbacher, U., Gächter, S., Fehr, E. 2001. Are people conditionally cooperative? Evidence from a public goods experiment. *Economic Letters* 71:397 – 404.
- Fehr, E., Schmidt, K. 1999. A Theory of Fairness, Competition, and Cooperation. *Quarterly Journal of Economics*, 114(3): 817 – 868.

- Gächter, S., Herrmann, B. 2009. Reciprocity, culture and human cooperation: previous insights and a new cross-cultural experiment. *Philosophical Transactions of the Royal Society B*, 364:791 – 806.
- Kymlicka, W. 1990. *Contemporary Political Philosophy*. Published in the United States: Oxford University Press Inc., New York.
- Lange, A., Vogt, C., Ziegler, A. 2007. On the importance of equity in international climate policy: An empirical analysis. *Energy Economics* 29:545-562.
- Lange, A., Löschel, A., Vogt, C., Ziegler, A. 2010. On the self-interested use of equity in international climate negotiations. *European Economic Review* 54: 359 – 375.
- Ledyard, J. 1995. Public goods: A survey of experimental research. In J. H. Kagel and A.E. Roth (eds.), *The Handbook of Experimental Economics*, Princeton University Press.
- Liberman, V., Samuels, S., Ross, L. 2004. The Name of the Game: Predictive Power of Reputations Versus Situational Labels in Determining Prisoner's Dilemma Game Moves. *Personality and Social Psychology Bulletin*, 30: 1175 – 1185.
- Loewenstein, G. 1999. Experimental Economics from the Vantage-Point of Behavioural Economics. *The Economic Journal*, 109: 25-34.
- Milinski, M., Sommerfeld, R., Krambeck, H., Reed, F., Marotzke, J. 2008. The collective-risk social dilemma and the prevention of simulated dangerous climate change. *PNAS*, 105(7): 2291–2294.
- Rawls, J. 1971. *A Theory of Justice*. Harvard University Press, Cambridge, Massachusetts
- Ringius, L., Torvanger, A., Holtmark, B. 1998. Can multi-criteria rules fairly distribute climate burdens? OECD results from three burden sharing rules. *Energy Policy* 26(10): 777 – 793.

- Ringius, L., Torvanger, A., Underdal, A. 2002. Burden Sharing and Fairness Principles in International Climate Policy. *International Environmental Agreements: Politics, Law and Economics* 2: 1-22.
- Saran, S. 2010. Irresistible forces and immovable objects: a debate on contemporary climate politics. *Climate Policy* 10:678 – 683.
- Tavonia, A., Dannenberg, A., Kallis, G., Löschel, A. 2011. Inequality, Communication, and the Avoidance of Disastrous Climate Change in a Public Goods Game. *PNAS Early Edition*.
- Torvanger, A., Ringius, L. 2002. Criteria for Evaluation of Burden-sharing Rules in International Climate Policy. *International Environmental Agreements: Politics, Law and Economics* 2:221 – 235.
- Torvanger, A., Godal, O. 2004. An Evaluation of Pre-Kyoto Differentiation Proposals for National Greenhouse Gas Abatement Targets. *International Environmental Agreements: Politics, Law and Economics* 4: 65–91.
- United Nations Framework Convention on Climate Change, 1992, Article 3. Available online at: <http://unfccc.int/resource/docs/convkp/conveng.pdf>; last accessed: 21 April 2013.
- Visser, M., Burns, J. 2013. Inequality, Social Sanctions and Cooperation within South African Fishing. Southern Africa Labour and Development Research Unit, Working Paper Series, No. 117.
- Winkler, H., Tyani, L., Spalding-Fecher, R. 2001. What could potential carbon emissions allocation schemes and targets mean for South Africa? Energy and Development Research Centre Report Series, University of Cape Town.
- World Economic Outlook Database. 2010. International Monetary Fund. Available online at: www.imf.org.

Appendix A. Sample statistics

Table A1. Students' majors (%)

	Subjects n=255	US n=51	EU n=51	China n=51	India n=51	SA n=51
Accounting	0.04		0.02			0.16
Actuarial science	0.01					0.06
Anthropology	0.00		0.02			
Archaeology	0.02			0.12		
Chemistry	0.00					0.02
Computer science	0.02	0.02				0.06
Economics	0.23	0.02	0.18		0.78	0.16
Education	0.00			0.02		
Engineering	0.07			0.10	0.02	0.24
Environment	0.05	0.02	0.18	0.06		
Film and media	0.01					0.04
Finance	0.01		0.02	0.02		0.02
Geography	0.02		0.04	0.08		
Geology	0.02			0.10		
Geomatics	0.00			0.02		
Geophysics	0.03	0.06		0.04		0.04
Health sciences	0.00		0.02			
History	0.00		0.02			
Human resources	0.00					0.02
Information systems	0.01			0.06		
Journalism	0.06	0.02		0.10	0.20	
Language & lit.	0.02		0.02	0.10		
Law	0.01			0.04		
Life sciences	0.05	0.14	0.12	0.02		
Management	0.02		0.02	0.02		0.04
Maths & statistics	0.02		0.02	0.06		
Palaeontology	0.07	0.10	0.18	0.02		0.06
Politics	0.01	0.02		0.02		0.02
Psychology	0.12	0.49	0.08			
Public policy	0.00		0.02			
Research methods	0.00					0.02
Sociology	0.02		0.04			0.06
Urban planning	0.03	0.12	0.02	0.02		

Appendix B. Experiment instructions (extract)

Introduction

Thank you for participating in this experiment.

This research is being conducted by researchers from the Environmental Policy Research Unit at the School of Economics, University of Cape Town.

Climate change is about sharing the responsibility to reduce global greenhouse gases and this study examines how the responsibility to reduce global emissions could be divided among different countries. The countries/regions represented in this study are: the United States (US), the European Union (EU), China, India and South Africa (SA).

The experiment is played in groups of five. Each group consists of one person **from each** of the five countries/regions represented in the game: namely, the US, EU, China, India and SA.

All the answers you provide will remain confidential. You will **never** be named as a participant in this study.

You will be paid for your participation: you will earn a participation fee of \$5. In addition to this, you may earn more money depending on your decisions and the decisions of the other players in your group. During the experiment we will not talk of dollars, but rather of ECUs. The ECUs you earn during the experiment will be converted to dollars at the following rate:

1 ECU = \$0.2

Once all the surveys are completed and your earnings have been calculated, your total (dollar) earnings will be converted into your local currency using Purchasing Power Parity conversion rates from the *International Monetary Fund (IMF) World Economic Outlook (WEO) database*.

As each group consists of subjects from all over the world, we will not be able to pay you as soon as you submit this questionnaire. Rather, once all the questionnaires have been completed, **without looking at your decisions and answers**, we will **randomly** put you into groups of 5 in order to calculate your payoffs. Once this has been done, we will notify you via email of the results and your payoff.

(For South Africa) We will use cash cheques to pay you your earnings and participation fee.

(For US, EU, China and India) We will use PayPal (www.paypal.com) to pay you your earnings and participation fee. Note that your name and email address will only be used for payment purposes.

The experiment consists of 4 parts and a short survey; and should take approximately an hour and a half to complete – however you can take as much time as you like (there is no time limit). Please note that if you close this window before finishing the experiment, all your information will be lost. So please make sure that you have enough time to complete the experiment before you start.

Once again, **thank you for your participation!**

Part 1

You have been allocated to a group of 5 people.

Each person in your group is acting as a representative for one of the following countries/regions: US, EU, China, India and SA.

You are representing *South Africa*

The table below reflects the past, present and most recent projected future emissions of your group.

At a recent Climate Change Summit, policy-makers from the US, EU, China, India and SA pledged to reduce greenhouse gas emissions to 62 MtCO₂ by 2050. This is half of the emissions level in 1990.

Note that no individual country targets have been agreed to!

Your group must now decide how to meet this target!

Because 2006 is the last date of actual data (it is not a projection), it has been used as the basis for your groups' negotiations. Your goal as a group is to reduce emissions by 115 MtCO₂ by 2050:
 $177 \text{ MtCO}_2 - 115 \text{ MtCO}_2 = 62 \text{ MtCO}_2$

Therefore, in Part 1 of the experiment, your group must decide how you (as a group) are going to reduce emissions by 115 MtCO₂.

Past present and most recent projected future emissions:

Country	1980	1985	1990	1995	2000	2006	2010*	2015*	2020*	2025*	2030*
US	47	46	50	52	58	58	57	58	58	58	58
EU	45	42	42	40	40	41	40	40	39	39	38
China	14	18	23	32	33	62	69	88	100	110	117
India	3	4	6	8	10	13	15	18	22	27	33
SA	2	2	3	3	3	3	4	4	4	5	5
<i>Total</i>	<i>111</i>	<i>112</i>	<i>124</i>	<i>135</i>	<i>144</i>	<i>177</i>	<i>185</i>	<i>208</i>	<i>223</i>	<i>239</i>	<i>251</i>

Note: * indicates projected emissions

From the table you can see that emissions in the US and EU have peaked, while China and India's emissions are projected to rise between now and 2030. While SA's emissions are also projected to rise, SA represents a very small share of the group's total emissions.

Initial endowment

Each player in your group receives an amount of ECUs. You must decide what to do with the ECUs you have been given. You can either:

- (i) Put all the ECUs into *your* private account
- (ii) Put all the ECUs into a mitigation account
- (iii) Divide the ECUs between the private account and the mitigation account

What is mitigation? Mitigation is an approach that decreases greenhouse gas emissions. An example of this would be using renewable energy sources for electricity generation instead of fossil fuels. By lowering the quantity of greenhouse gases in the atmosphere you reduce the *severity of climate change*. Because there are no borders in the atmosphere, a reduction in emissions by one country is shared by all countries. So everyone in your group will benefit from mitigation.

So, if you put ECUs in the **mitigation account**, you are **investing in mitigation**.

The countries/regions represented in the game have different levels of wealth. The ECUs you are given at the start of this game represent this wealth. As such, players representing developed countries start the experiment with **more** ECUs. The amount of ECUs each player starts the game with is shown below:

Country/Region	ECUs
United States	70
European Union	70
China	50
India	25
South Africa	15

Return from the mitigation account

As we have mentioned, the benefits from investing in mitigation are shared equally between all the players in your group!

The number of ECUs **contributed** to the mitigation account is your groups' **investment in mitigation**.

This amount will be **multiplied** by an *emissions factor* of **1.5** to determine the **emissions reduction of the group**.

For example: Assume that your group puts a total of 80 ECUs in the mitigation account. This means that your group has invested 80 ECUs in mitigation. These 80 ECUs are multiplied by an emissions factor of 1.5. This means that your group has reduced emissions by 120 MtCO₂.

The reduction of emissions leads to global benefits which are equally shared by all countries. This is the global benefit of keeping the temperature below 2 degrees centigrade – which is the threshold for catastrophic climate change. Such benefits include reduced climate variability and a reduced probability of environmental disaster.

Because your group shares the benefits of mitigation, the total number of ECUs in the mitigation account (after being multiplied by the emission factor of 1.5) is then **divided equally** among the group, **irrespective of how much each member personally put in the mitigation account.**

For every 1 ECU contributed to the mitigation account, each of the five group members receives 0.3 ECUs:

$$1 \text{ ECU} \times 1.5 = 1.5 \text{ ECUs} \equiv 1.5 \text{ MtCO}_2$$

$$\frac{1.5 \text{ ECUs}}{5} = 0.3 \text{ ECUs}$$

So, every ECU contributed to the mitigation account (by you or one of your group members) reduces emissions by 1.5 MtCO₂ and earns you and every person in your group a return of 0.3 ECUs.

As your **group** is trying to reduce emissions by **115 MtCO₂**, there must be at least 115 ECUs in the mitigation account **after** the ECUs are multiplied by the emissions factor of 1.5. **This means that at least 77 ECUs must be contributed to the mitigation account by your group:**

$$77 \text{ ECUs} \times 1.5 = 115.5 \text{ ECUs} \equiv 115.5 \text{ MtCO}_2$$

Later, we will ask you how many ECUs (if any) you would like to contribute to the mitigation account.

Return from the private account

While the benefits of investing in mitigation are shared between all the members in your group, the benefit of contributions to the private account go only to you (as your country's representative). As such, **you keep whatever you contributed to the private account.**

So, every ECU invested in the private account earns you a return of 1 ECU.

Total return: if your group meets the reduction target

If your group meets the emission reduction target, your income is calculated as follows:

- You keep the ECUs in your private account
- The ECUs in the mitigation account (after being multiplied by the emissions factor of 1.5) are divided equally between all 5 members in the group

Total return: if your group FAILS to meet the reduction target

Your group fails to meet the target if the number of ECUs in the mitigation account (after being multiplied by the emissions factor of 1.5) is **less than 115**. In other words, the group fails to meet the target if less than 77 ECUs are contributed to the mitigation account.

If the group fails to meet the abatement target, there will be a temperature warming above 2 degrees centigrade.

In this case, each player will have to use of portion of the funds in their private account for investment in adaptation and to fund disaster relief.

As such, **if the emission reduction target is not met, each player loses a portion of the ECUs in his/her private account.**

Developing countries will need more severe adaptation measures and will likely be hit hardest by climate change. As such, players representing developing countries lose a larger share of the ECUs in their private account relative to players in the group who represent developed countries.

The portion deducted from each player's private account (**if the group fails to meet the emission reduction target**) is as follows:

Country/Region	Portion deducted from the private account if target is NOT met
United States	25%
European Union	25%
China	50%
India	50%
South Africa	50%

Finally, if the **group fails to meet** the emissions target, in addition to each player losing a share of the ECUs in his/her private account, **there will be no return from investing in mitigation:** the ECUs in the mitigation account **are not** divided up among the 5 group members).

Examples [A number of examples were provided to participants. Only 3 are replicated here.]

Example 1

Your group's target is to reduce emissions by 115 MtCO₂. Use the information in the table below to calculate the amount of ECUs invested in mitigation, the emissions reduction of the group, the income from the mitigation and private accounts and, finally, each player's total income.

Country	Endowment (ECUs)	Investment in mitigation
US	70	20
EU	70	25
China	50	15
India	25	15
SA	15	10

Investment in mitigation

$$20_{US} + 25_{EU} + 15_{China} + 15_{India} + 10_{SA} = 85 \text{ ECUs invested in mitigation}$$

Emissions reduced:

$$= 85 \text{ ECUs} \times 1.5$$

$$= 127.5 \text{ ECUs} \equiv 127.5 \text{ MtCO}_2$$

Emissions have been reduced by 127.5 MtCO₂. The group has met the target of reducing emissions by 115 MtCO₂. As such, players will earn a return from mitigation and will not lose any portion of the income in their private accounts.

Return from mitigation account:

$$\frac{127.5 \text{ ECUs}}{5} = 25.5 \text{ ECUs}$$

Country	Endowment (ECUs)	Investment in mitigation	Return from mitigation	Return from private acc.	Total income (ECUs)
US	70	20	25.5	50	75.5
EU	70	25	25.5	45	70.5
China	50	15	25.5	35	60.5
India	25	15	25.5	10	35.5
SA	15	10	25.5	5	30.5

Note:

The return from the private account is calculated as follows: Endowment – Investment in mitigation

Total income is calculated as follows: Return from mitigation + Return from private account

Example 2

Your group's target is to reduce emissions by 115 MtCO₂. Use the information in the table below to calculate the amount of ECUs invested in mitigation, the emissions reduction of the group, the income from the mitigation and private accounts and, finally, each player's total income.

Country	Endowment (ECUs)	Investment in mitigation
US	70	10
EU	70	15
China	50	8
India	25	6
SA	15	5

Investment in mitigation

$$10_{US} + 15_{EU} + 8_{China} + 6_{India} + 5_{SA} = 44 \text{ ECUs invested in mitigation}$$

Emissions reduced:

$$= 44 \text{ ECUs} \times 1.5$$

$$= 66 \text{ ECUs} \equiv 66 \text{ MtCO}_2$$

Emissions have been reduced by 66 MtCO₂. **Note: the group has not met the target of reducing emissions by 115 MtCO₂.** In this case, players do **not** earn a return from mitigation and **will** lose a portion of the ECUs in their private accounts.

Return from mitigation account:

$$= 0 \text{ ECUs}$$

Country	Endowment (ECUs)	Investment in mitigation	Return from mitigation	Investment in private acc.	% deducted from private acc.	ECUs deducted from private account	Return from private account	Total income (ECUs)
US	70	10	0	60	25%	15	45	45.0
EU	70	15	0	55	25%	13.8	41.2	41.2
China	50	8	0	42	50%	21	21	21.0
India	25	6	0	19	50%	9.5	9.5	9.5
SA	15	5	0	10	50%	5	5	5.0

Note:

The investment in the private accounts is calculated as: Endowment – Investment in mitigation

Return from the private account is calculated as: Investment in private account – ECUs deducted from private account

Total income is calculated as follows: Return from mitigation + Return from private account

Example 3

In this example, we introduce a table which summarizes the total income of one country, given its mitigation and the collective mitigation of the other countries in the group. We will now go through a similar example as the ones before, but show how each player can verify their total income using the table. (Later, when you decide how many ECUs to contribute to the mitigation account, we will provide you with tables like this to help you make your decision.)

Your group's target is to reduce emissions by 115 MtCO₂. Use the information in the table below to calculate the amount of ECUs invested in mitigation, the emissions reduction of the group, the income from the mitigation and private accounts and, finally, each player's total income.

Country	Endowment (ECUs)	Investment in mitigation
US	70	39
EU	70	51
China	50	23
India	25	7
SA	15	5

Investment in mitigation

$$39_{\text{US}} + 51_{\text{EU}} + 23_{\text{China}} + 7_{\text{India}} + 5_{\text{SA}} = 125 \text{ ECUs invested in mitigation}$$

Emissions reduced:

$$= 125 \times 1.5$$

$$= 187.5 \text{ tokens} \equiv 187.5 \text{ MtCO}_2$$

Emissions have been reduced by 187.5 MtCO₂. The group has met the target of reducing emissions by 115 MtCO₂. As such, players will earn a return from mitigation and will not lose any ECUs from their private accounts.

Return from mitigation account:

$$\frac{187.5}{5} = 37.5 \text{ ECUs}$$

Country	Endowment (ECUs)	Investment in mitigation	Return from mitigation	Return from private acc.	Total income (ECUs)
US	70	39	37.5	31	68.5
EU	70	51	37.5	19	56.5
China	50	23	37.5	27	64.5
India	25	7	37.5	18	55.5
SA	15	5	37.5	10	47.5

Note:

The return from the private account is calculated as follows: Endowment – Investment in mitigation

Total income is calculated as follows: Return from mitigation + Return from private account

Using the table below, verify that South Africa's total income is 47.5 ECUs:

		Investment in mitigation by South Africa			
		0	5	10	15
		(min)			(max)
Collective investment in mitigation by US, EU, China and India	0	7.5	5.0	2.5	0.0
	40	7.5	5.0	2.5	0.0
	80	39.0	35.5	32.0	28.5
	120	51.0	47.5	44.0	40.5
	160	63.0	59.5	56.0	52.5
	200	75.0	71.5	68.0	64.5
	215	79.5	76.0	72.5	69.0

Part 1 continued

To help you make your decision, the payoff tables from the previous examples are replicated for you below.

Payoff tables (Total income, by country):

		Investment in mitigation by the US							
		0	10	20	30	40	50	60	70
Collective investment in mitigation by the EU, China, India and SA	0	52.5	45.0	37.5	30.0	22.5	15.0	7.5	0.0
	40	52.5	45.0	37.5	30.0	54.0	47.0	40.0	33.0
	80	94.0	87.0	80.0	73.0	66.0	59.0	52.0	45.0
	120	106.0	99.0	92.0	85.0	78.0	71.0	64.0	57.0
	160	118.0	111.0	104.0	97.0	90.0	83.0	76.0	69.0

		Investment in mitigation by the EU							
		0	10	20	30	40	50	60	70
Collective investment in mitigation by the US, China, India and SA	0	52.5	45.0	37.5	30.0	22.5	15.0	7.5	0.0
	40	52.5	45.0	37.5	30.0	54.0	47.0	40.0	33.0
	80	94.0	87.0	80.0	73.0	66.0	59.0	52.0	45.0
	120	106.0	99.0	92.0	85.0	78.0	71.0	64.0	57.0
	160	118.0	111.0	104.0	97.0	90.0	83.0	76.0	69.0

		Investment in mitigation by China					
Collective		0	10	20	30	40	50
investment in mitigation by the US, EU, India and SA	0	25.0	20.0	15.0	10.0	5.0	0.0
	40	25.0	20.0	15.0	10.0	34.0	27.0
	80	74.0	67.0	60.0	53.0	46.0	39.0
	120	86.0	79.0	72.0	65.0	58.0	51.0
	160	98.0	91.0	84.0	77.0	70.0	63.0
	180	104.0	97.0	90.0	83.0	76.0	69.0

		Investment in mitigation by India					
Collective		0	5	10	15	20	25
investment in mitigation by the US, EU, China and SA	0	12.5	10.0	7.5	5.0	2.5	0.0
	40	12.5	10.0	7.5	5.0	2.5	0.0
	80	49.0	45.5	42.0	38.5	35.0	31.5
	120	61.0	57.5	54.0	50.5	47.0	43.5
	160	73.0	69.5	66.0	62.5	59.0	55.5
	200	85.0	81.5	78.0	74.5	71.0	67.5
	205	86.5	83.0	79.5	76.0	72.5	69.0

		Investment in mitigation by SA			
Collective		0	5	10	15
investment in mitigation by the US, EU, China and India	0	7.5	5.0	2.5	0.0
	40	7.5	5.0	2.5	0.0
	80	39.0	35.5	32.0	28.5
	120	51.0	47.5	44.0	40.5
	160	63.0	59.5	56.0	52.5
	200	75.0	71.5	68.0	64.5
	215	79.5	76.0	72.5	69.0

Your group must reduce emissions by 115 MtCO₂.

This means that there must be at least 115 ECUs in the mitigation account **after** the ECUs are multiplied by the emissions factor of 1.5. **This means that at least 77 ECUs must be contributed to the mitigation account by your group:**

You, as your county representative, must decide how many ECUs to contribute to the mitigation account.

Please use the payoff tables above to help you make your decision. Additional information is replicated in the tables below:

MtCO₂, by country:

Country	1980	1985	1990	1995	2000	2006	2010*	2015*	2020*	2025*	2030*
US	47	46	50	52	58	58	57	58	58	58	58
EU	45	42	42	40	40	41	40	40	39	39	38
China	14	18	23	32	33	62	69	88	100	110	117
India	3	4	6	8	10	13	15	18	22	27	33
SA	2	2	3	3	3	3	4	4	4	5	5
<i>Total</i>	<i>111</i>	<i>112</i>	<i>124</i>	<i>135</i>	<i>144</i>	<i>177</i>	<i>185</i>	<i>208</i>	<i>223</i>	<i>239</i>	<i>251</i>

Note: * indicates projected emissions

Country information:

Country/region	ECUs	Portion deducted from the private account if target is NOT met
United States	70	25%
European Union	70	25%
China	50	50%
India	25	50%
South Africa	15	50%

Please indicate the number of ECUs you, as the representative for *South Africa*, wish to contribute to the mitigation account:

Also, please indicate the number of ECUs you think your group members should contribute to the mitigation account:

United States:	<input type="text"/>	(Can only invest a maximum of 70 ECUs)
European Union:	<input type="text"/>	(Can only invest a maximum of 70 ECUs)
China:	<input type="text"/>	(Can only invest a maximum of 50 ECUs)
India	<input type="text"/>	(Can only invest a maximum of 25 ECUs)
South Africa:	<input type="text"/>	(Can only invest a maximum of 15 ECUs)

Part 2

You are now faced with a similar scenario to that of Part 1. Once again, each player in your group is endowed with the following ECUs:

Country	Endowment (ECUs)
US	70
EU	70
China	50
India	25
SA	15

As before, your group must reduce emissions by 115 MtCO₂.

To recap: this means that there must be at least 115 ECUs in the mitigation account **after** the ECUs are multiplied by the emissions factor of 1.5. **This means that at least 77 ECUs must be contributed to the mitigation account by your group:**

Except now, you no longer represent *South Africa!*

We will randomly assign you to a country/region without looking at your decision.

You, as your (unknown) country representative, must decide how many ECUs to contribute to the mitigation account.

[Participant are provided with the same summary information as in Part 1]

Remember that you no longer represent *South Africa!*

Please indicate the number of ECUs you think each country/region should contribute to the mitigation account; you will be randomly assigned as the representative for one of these countries:

United States:	<input type="text"/>	(Can only invest a maximum of 70 ECUs)
European Union:	<input type="text"/>	(Can only invest a maximum of 70 ECUs)
China:	<input type="text"/>	(Can only invest a maximum of 50 ECUs)
India	<input type="text"/>	(Can only invest a maximum of 25 ECUs)
South Africa:	<input type="text"/>	(Can only invest a maximum of 15 ECUs)

Part 3

You are now faced with a similar scenario to the ones before. Once again, each player in your group is endowed with the following ECUs:

Country	Endowment (ECUs)
US	70
EU	70
China	50
India	25
SA	15

As in Part 1, you are once again representing South Africa.

The table below reflects the past, present and most recent projected future emissions of your group:

Country	1980	1985	1990	1995	2000	2006	2010*	2015*	2020*	2025*	2030*
US	47	46	50	52	58	58	57	58	58	58	58
EU	45	42	42	40	40	41	40	40	39	39	38
China	14	18	23	32	33	62	69	88	100	110	117
India	3	4	6	8	10	13	15	18	22	27	33
SA	2	2	3	3	3	3	4	4	4	5	5
<i>Total</i>	<i>111</i>	<i>112</i>	<i>124</i>	<i>135</i>	<i>144</i>	<i>177</i>	<i>185</i>	<i>208</i>	<i>223</i>	<i>239</i>	<i>251</i>

Note: * indicates projected emissions

Remember that your group has pledged to reduce emissions by 115 MtCO₂ to 62 MtCO₂ by 2050.

Your group must reduce emissions by 115 MtCO₂ to meet its pledge. Therefore your group has an **abatement burden** of 115 MtCO₂.

As your group will be able to collectively emit 62 MtCO₂ in 2050, your group has a **global emission entitlement** of 62 MtCO₂.

There are four burden-sharing principles that you can use to decide how your group is going to reduce emissions by 115 MtCO₂ and share the global emission entitlement of 62 MtCO₂.

These burden-sharing principles are:

Equal per capita entitlement to emissions: If the population of your country represents x% of the global population, you are entitled to x% of global emissions entitlements.

Equal percentage reduction of current emissions: If your country's current emissions amount to x% of global emissions, you should get x% of global emissions entitlements.

Historical polluter-pays rule: the abatement burden is allocated according to **historical** responsibility (1980 – 2000). If your country’s emissions between 1980 and 2000 amount to x% of global emissions in that time, you are responsible for x% of the reduction target.

Future polluter-pays rule: the abatement burden is allocated according to **future** responsibility (2010 – 2030). If your country’s projected emissions between 2010 and 2030 will amount to x% of projected global emissions in that time, you are responsible for x% of the reduction target.

Of course these principles have different implications for the amount each country **must invest in mitigation** and therefore your **total income**.

The tables below show the emission reduction and total payoff for each country when **the entire group** uses a particular burden-sharing formula to meet the emission reduction target.

Payoffs and contributions under each burden-sharing principle:

If all group members use the principle of **equal per capita emissions**:

Country	% of population	Share of entitlement	ECUs	Current emissions	Emissions in 2050	ECUs inv. in mitigation	Total payoff
US	0.09	6	70	58	6	35	60
EU	0.15	9	70	41	9	21	74
China	0.40	25	50	62	25	25	50
India	0.34	21	25	13	21	0	50
SA	0.01	1	15	3	1	1	38

If all group members use the principle of **equal percentage reduction of current emissions**:

Country	Current emissions	Share of current emissions	Share of entitlement	ECUs	Emissions in 2050	ECUs inv. in mitigation	Total payoff
US	58	0.33	20	70	20	25	68
EU	41	0.23	14	70	14	18	75
China	62	0.35	22	50	22	27	46
India	13	0.07	4	25	4	6	42
SA	3	0.02	1	15	1	1	37

If all group members use the principle of **historical polluter-pays**:

Country	% of emissions 1980-2000	Share of burden	Current emissions	ECUs	Emissions in 2050	ECUs inv. in mitigation	Total payoff
US	0.40	46	58	70	12	31	62
EU	0.33	38	41	70	3	25	68
China	0.20	23	62	50	39	15	58
India	0.05	6	13	25	7	4	44
SA	0.02	2	3	15	1	2	36

If all group members use the principle of **future polluter-pays**:

Country	% of emissions 2010-2030	Share of burden	Current emissions	ECUs	Emissions in 2050	ECUs inv. in mitigation	Total payoff
US	0.26	30.0	58	70	28	20	73
EU	0.18	20.3	41	70	21	14	79
China	0.44	50.6	62	50	11	34	39
India	0.10	11.7	13	25	1	8	40
SA	0.02	2.3	3	15	1	2	36

You can see from the tables above that different principles imply different contributions to the mitigation account by **your** country. We summarize this information for you in the tables below:

US investment in mitigation under each principle:

Principle:	ECUs invested in mitigation:
Equal per capital emissions	35
Equal % reduction of current emissions	25
Historical polluter-pays	31
Future polluter-pays	20

EU investment in mitigation under each principle:

Principle:	ECUs invested in mitigation:
Equal per capital emissions	21
Equal % reduction of current emissions	18
Historical polluter-pays	25
Future polluter-pays	14

China investment in mitigation under each principle:

Principle:	ECUs invested in mitigation:
Equal per capital emissions	25
Equal % reduction of current emissions	27
Historical polluter-pays	15
Future polluter-pays	34

India investment in mitigation under each principle:

Principle:	ECUs invested in mitigation:
Equal per capital emissions	0
Equal % reduction of current emissions	6
Historical polluter-pays	4
Future polluter-pays	8

South Africa investment in mitigation under each principle:

Principle:	ECUs invested in mitigation:
Equal per capital emissions	1
Equal % reduction of current emissions	1
Historical polluter-pays	2
Future polluter-pays	2

Remember that your group has pledged to reduce emissions by 115 MtCO₂.

This means that there must be at least 115 ECUs in the mitigation account **after** the ECUs are multiplied by the emissions factor of 1.5. **This means that at least 77 ECUs must be contributed to the mitigation account by your group.**

Using the tables above, you can see that there are certain instances when the target will not be met. Let's assume that each of the player's in your group chooses the principle listed in the table below. Each country's associated investment in mitigation is also shown in the table.

Country/Region	Burden-sharing principle	Contribution to the mitigation account
United States	Future polluter pays	20
European Union	Future polluter pays	14
China	Historical polluter pays	15
India	Equal per capital emissions	0
South Africa	Equal per capital emissions	1

A total of 50 ECUs are contributed to the mitigation account. By multiplying this with the emissions factor of 1.5, we can see that emissions have been reduced by 75 MtCO₂. This means the group has not met the target of reducing emissions by 115 MtCO₂.

Remember that if the target is not met, there is no income from mitigation and each player loses a portion of the ECUs in their private account. The portion deducted from each player's private account (**if the group fails to meet the emission reduction target**) is shown below:

Country/Region	Portion deducted from the private account if target is NOT met
United States	25%
European Union	25%
China	50%
India	50%
South Africa	50%

After considering all the information given above, please choose the burden-sharing principle that you, as the country representative for *South Africa; the United States; the European Union; China; India*, would like to use to meet the target:

Note: you can only choose **one** fairness principle

- | | |
|--------------------------|---|
| <input type="checkbox"/> | Equal per capita entitlement to emissions |
| <input type="checkbox"/> | Equal percentage reduction of current emissions |
| <input type="checkbox"/> | Historical polluter-pays rule |
| <input type="checkbox"/> | Future polluter-pays rule |

University of Cape Town

Part 4

You are now faced with a similar scenario to the one in Part 3. Once again, each player in your group is endowed with the following ECUs:

Country	Endowment (ECUs)
US	70
EU	70
China	50
India	25
SA	15

As before, your group must reduce emissions by 115 MtCO₂ to 62 MtCO₂ by 2050.

As before, you must choose the burden-sharing principle that you would like to use to meet the target.

Except now, you no longer represent *South Africa!*

We will randomly assign you to a country/region without looking at your decision.

The table below reflects the past, present and most recent projected future emissions of your group:

Country	1980	1985	1990	1995	2000	2006	2010*	2015*	2020*	2025*	2030*
US	47	46	50	52	58	58	57	58	58	58	58
EU	45	42	42	40	40	41	40	40	39	39	38
China	14	18	23	32	33	62	69	88	100	110	117
India	3	4	6	8	10	13	15	18	22	27	33
SA	2	2	3	3	3	3	4	4	4	5	5
<i>Total</i>	<i>111</i>	<i>112</i>	<i>124</i>	<i>135</i>	<i>144</i>	<i>177</i>	<i>185</i>	<i>208</i>	<i>223</i>	<i>239</i>	<i>251</i>

Note: * indicates projected emissions

To recap:

There are four burden-sharing principles that you can use to decide how your group is going to reduce emissions by 115 MtCO₂ and share the global emission entitlement of 62 MtCO₂.

These burden-sharing principles are:

Equal per capita entitlement to emissions: If the population of your country represents x% of the global population, you are entitled to x% of global emissions entitlements.

Equal percentage reduction of current emissions: If your country's current emissions amount to x% of global emissions, you should get x% of global emissions entitlements.

Historical polluter-pays rule: the abatement burden is allocated according to **historical** responsibility (1980 – 2000). If your country’s emissions between 1980 and 2000 amount to x% of global emissions in that time, you are responsible for x% of the reduction target.

Future polluter-pays rule: the abatement burden is allocated according to **future** responsibility (2010 – 2030). If your country’s projected emissions between 2010 and 2030 will amount to x% of projected global emissions in that time, you are responsible for x% of the reduction target.

Of course these principles have different implications for the amount each country **must invest in mitigation** and therefore your **total income**.

[Participant are provided with the same summary information as in Part 3]

Remember that you no longer represent South Africa.

We will randomly assign you to a country without looking at your decision.

Please indicate which of the fairness principles listed below you, as your (unknown) country representative, would like to use to meet the target:

Note: you can only choose **one** fairness principle

<input type="checkbox"/>	Equal per capita entitlement to emissions
<input type="checkbox"/>	Equal percentage reduction of current emissions
<input type="checkbox"/>	Historical polluter-pays rule
<input type="checkbox"/>	Future polluter-pays rule

Appendix C. Best response given the cumulative contribution of remaining group members

Figure C1. United States

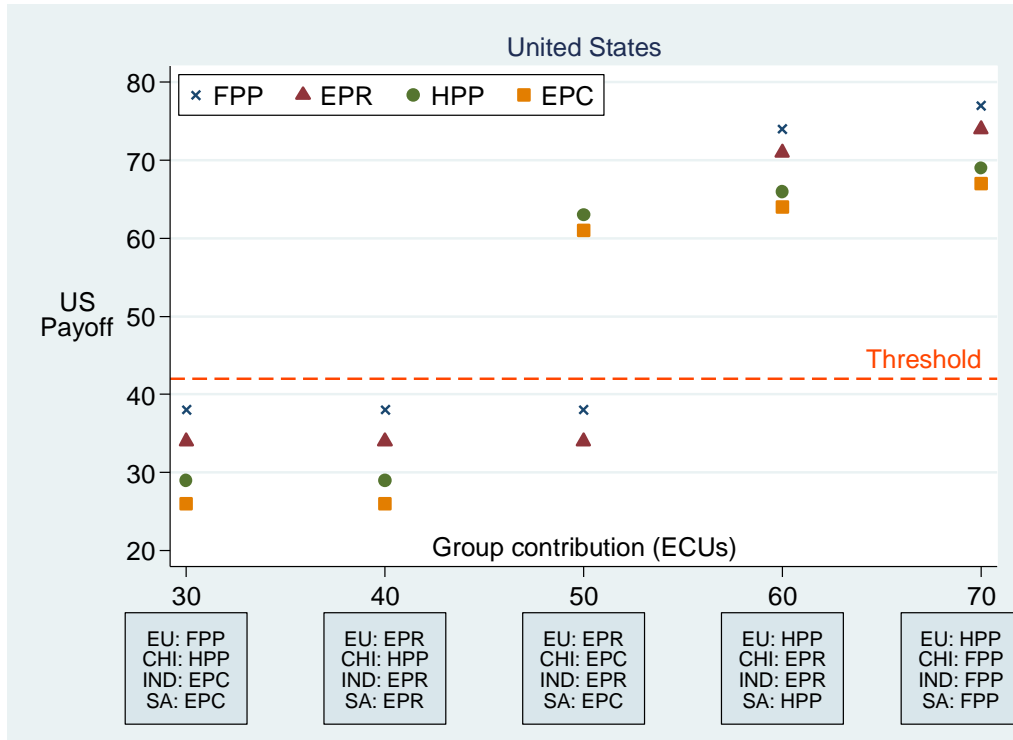


Figure C2. European Union

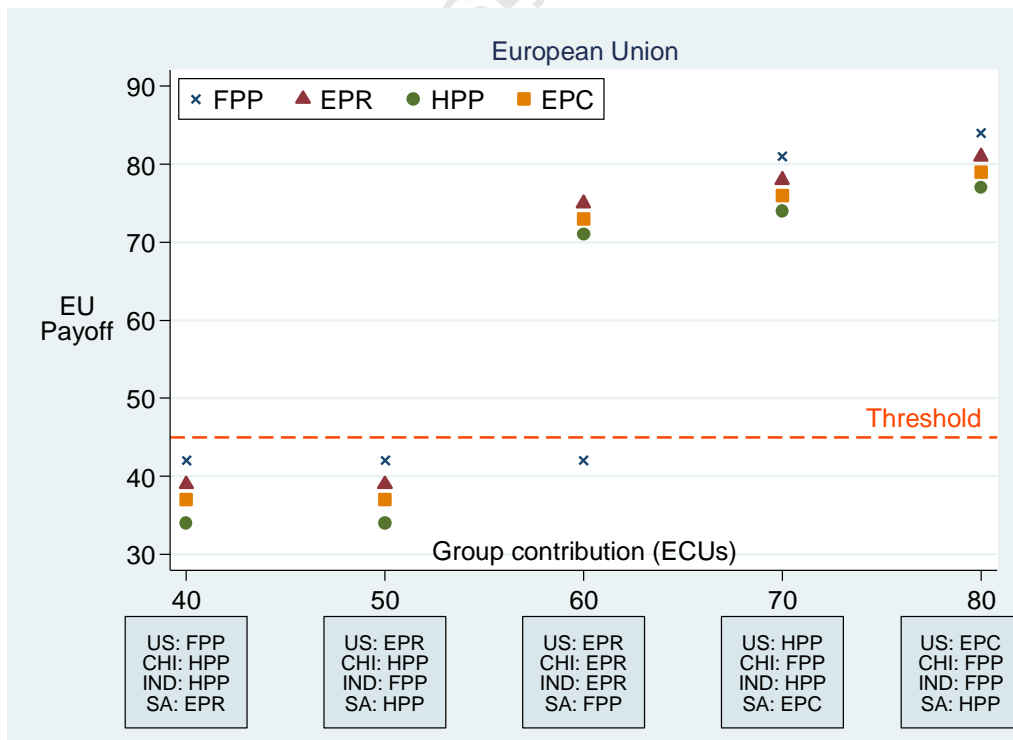


Figure C3. China

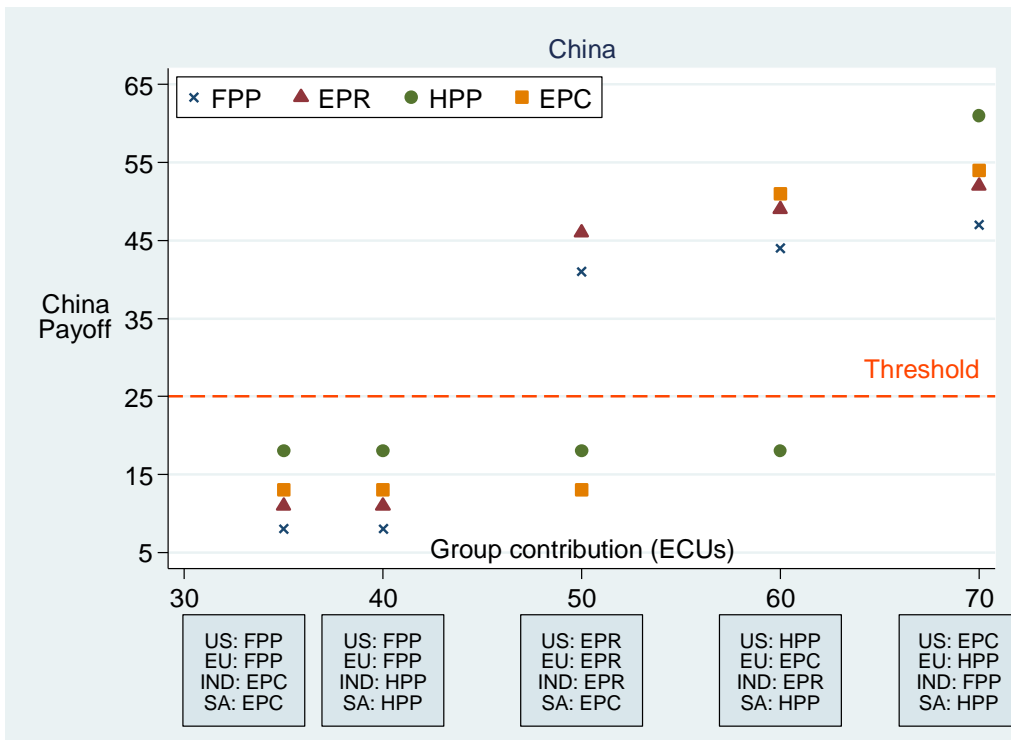


Figure C4. India

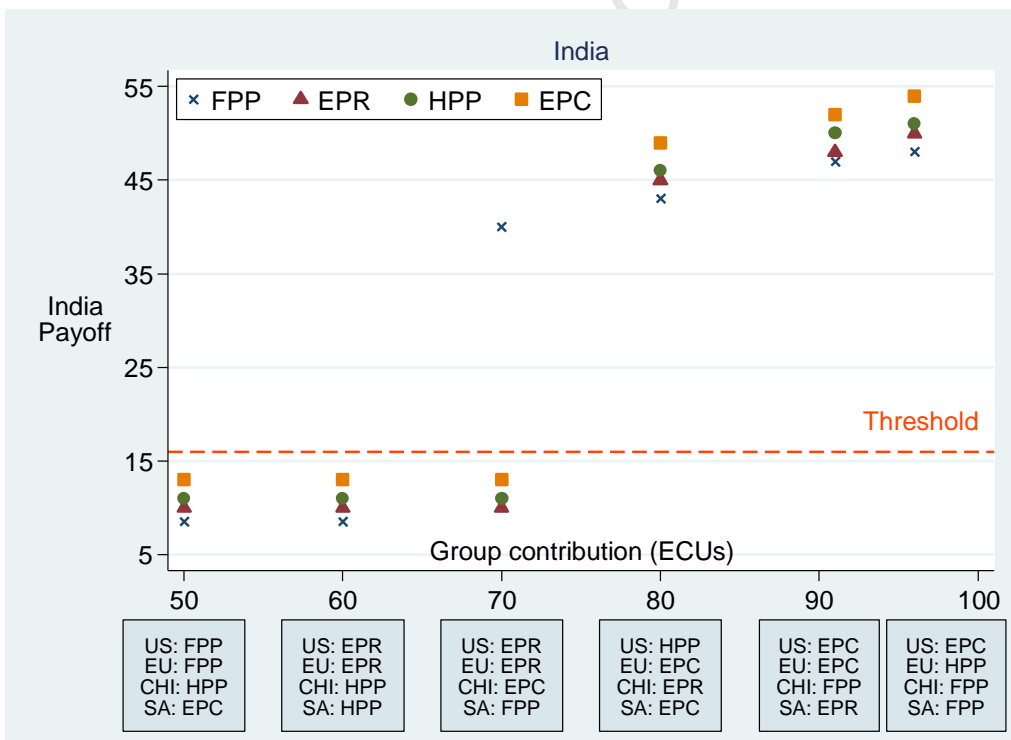
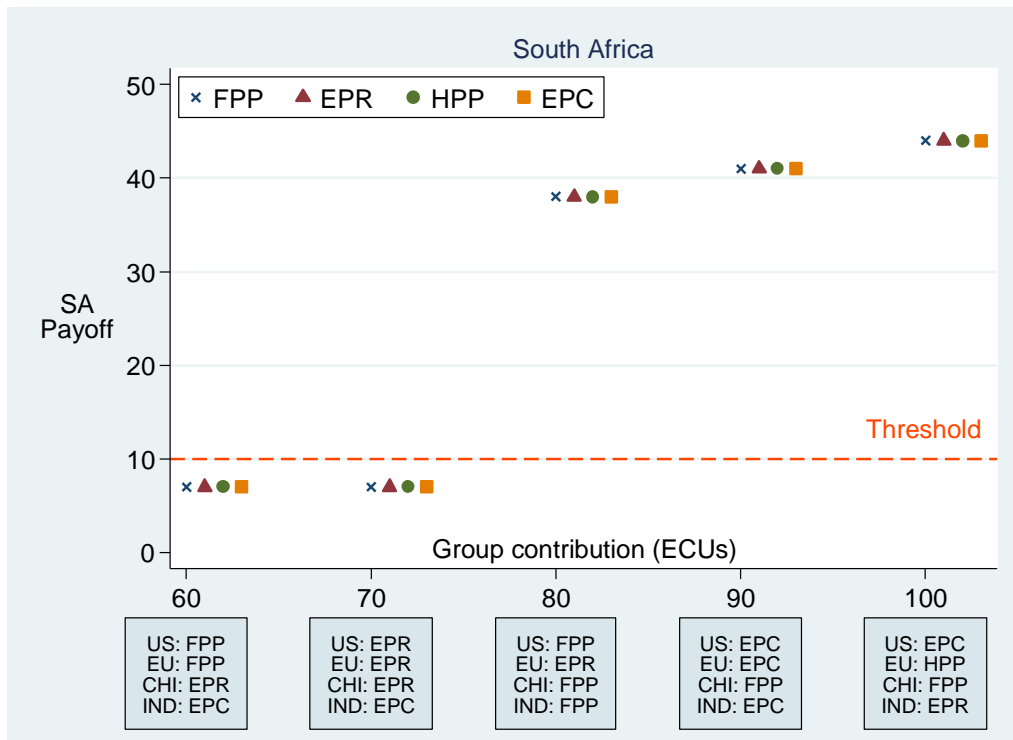


Figure C5. South Africa



Appendix D. Burden sharing principles

Table D1. Burden sharing principles, by nationality and sample

Burden-sharing principle	Participant nationality:									
	American		European		Chinese		Indian		South African	
	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>
Panel A: Students ($N = 255$, $n = 51$)										
Equal per capita	0.24	0.33	0.29	0.35	0.24	0.35	0.25	0.29	0.45	0.32
Equal % reduction	0.39	0.20	0.24	0.29	0.25	0.33	0.29	0.33	0.14	0.25
Historical polluter-pays	0.10	0.27	0.24	0.20	0.47	0.20	0.16	0.24	0.20	0.16
Future polluter-pays	0.27	0.20	0.24	0.16	0.04	0.12	0.29	0.14	0.22	0.27
Panel B: Practitioners ($N = 70$, $n = 14$)										
Equal per capita	0.21	0.36	0.57	0.43	0.21	0.57	0.21	0.21	0.21	0.14
Equal % reduction	0.36	0.36	0.07	0.14	0.07	0.07	0.21	0.50	0.21	0.50
Historical polluter-pays	0.21	0.29	0.36	0.43	0.71	0.29	0.50	0.29	0.43	0.29
Future polluter-pays	0.21	0.00	0.00	0.00	0.00	0.07	0.07	0.00	0.14	0.07

Notes:

- *ON*: own nationality; *RN*: Random nationality;
- N = sample or sub-sample size, n = number of individuals of a particular nationality (for example, there are 70 practitioners, 14 of each nationality).

Appendix E. Logistic regressions, historical and future polluter-pays principles (marginal effects at the mean)

Table E1. Logistic regressions, historical and future polluter-pays principles

	(1)	(2)	(3)	(4)
	Historical polluter-pays		Future polluter-pays	
	<i>Reference nationality: American</i>		<i>Reference nationality: Chinese</i>	
	<i>ON</i>	<i>RN</i>	<i>ON</i>	<i>RN</i>
Practitioner	0.166 (0.087)	0.081 (0.079)	-0.065 (0.054)	-0.147** (0.037)
American	-	-	0.501** (0.148)	0.040 (0.066)
European	0.223* (0.114)	-0.019 (0.071)	0.313* (0.153)	0.025 (0.064)
Chinese	0.494* (0.098)	-0.051 (0.068)	-	-
Indian	0.192 (0.113)	-0.019 (0.073)	0.409** (0.153)	0.002 (0.060)
South African	0.207 (0.112)	-0.078 (0.066)	0.316* (0.157)	0.140 (0.083)
Age	0.005 (0.006)	0.002 (0.005)	-0.009 (0.007)	0.001 (0.006)
Female	-0.025 (0.051)	0.000 (0.049)	-0.061 (0.038)	0.033 (0.033)

Notes:

- Robust standard errors in parentheses
- * and ** indicate significance at the 5% and 1% level, respectively
- Standard errors adjusted for clustering
- Results reported as marginal effects at the mean (MEM)
- For binary independent variables, the marginal effects indicate how the predicted probabilities change as the variable changes from 0 to 1

Cooperation and Climate Change: Can Communication Facilitate the Provision of Public Goods in Heterogeneous Agents?

Kerri Brick, Martine Visser and Zoe Van der Hoven

Abstract

International and domestic efforts to reduce greenhouse-gas emissions require a coordinated effort from heterogeneous actors. In this context, using a public good game with a climate change framing, the experiment reported here examines whether groups of heterogeneous individuals can meet a collective emission-reduction target through individual contributions. In terms of the framing, participants differ in terms of their marginal costs of abatement. The experiment consists of two games: a counterfactual baseline scenario examining the scope for voluntary cooperation and a communication game examining the role of stakeholder participation in facilitating cooperation. During the communication treatment, subjects are able to communicate with one another in order to coordinate contribution strategies. The results suggest that relying on the voluntary cooperation of individuals will not be sufficient to meet the mitigation target. Furthermore, while communication plays a role in promoting cooperation, even when heterogeneity is present, the non-binding nature of communication results in significant levels of free-riding. In particular, with the introduction of communication, two dominant contribution norms of free-riding and perfect-cooperation emerge. This outcome emphasises the importance of sanctioning opportunities in ensuring compliance with mitigation obligations.

Keywords: climate change; communication; contribution norm; heterogeneity; public good game

1 Introduction

Climate change mitigation exemplifies the public good dilemma: specifically, while there is broad consensus that a significant reduction of greenhouse gases is needed to reduce the risk of catastrophic climate change, as the benefits of (costly) mitigation are shared equally by all irrespective of individual contribution, there is considerable incentive to free ride (Hasson *et al.* 2010, Brekke and Johansson-Stenman 2008).

The current model for tackling climate change is a top-down approach whereby emission reduction targets are negotiated at multilateral climate talks and then implemented at a domestic-level by national governments through the formulation of climate policy. In both this international and domestic setting, no one country or individual can adequately provide the public good of mitigation, significant incentives for free-riding prevail and widespread participation is needed for climate policy to be effective (Ringius *et al.* 2002). With respect to the implementation of international environmental agreements, no single supranational authority can enforce cooperation and, in a domestic setting, in instances where cooperation can be enforced through penalties for non-compliance, monitoring, verification and enforcement is costly.

In this context, empirical evidence from public good games indicates that communication can be effective in facilitating a greater degree of cooperation among players (Gächter and Herrmann 2009, Oprea *et al.* 2013). As such, this article considers the extent to which communication is a useful mechanism for promoting compliance with climate policy. As it is not possible to alter the degree of communication in a real negotiation context, the research question is addressed in an experimental setting through a public good game with a climate change framing.

On a global scale, international environmental agreements like the Kyoto Protocol require countries with divergent levels of income and historical responsibility for emissions to agree on how best to distribute an abatement burden and apportion future entitlements to emissions. On a country level, reducing a national greenhouse-gas inventory requires a change in behaviour from both industry sectors and individuals – who are asymmetric with regard to income, energy consumption, abatement costs and historical emissions. As such, climate

change mitigation is a prime example of a public good dilemma in which stakeholders are heterogeneous.

In this context, stakeholder participation in domestic climate-policy-making processes and domestic climate negotiations occur in extremely complex environments amid large divergences in historical energy usage among different sectors of society, party-politics, special-interest lobbying, alternative developmental priorities and environmental objectives and concerns relating to social and distributive justice.¹ Despite this complexity, the need for public good provision (meeting a target) in this domestic setting is extremely important given that, as mentioned, while the current multilateral, top-down, rules-based approach of the Kyoto Protocol assigns each country a quantifiable and binding emission reduction target, each country itself formulates and implements its own domestic climate policy agenda. In this context, this article considers the role of communication (and by extension, stakeholder participation) in facilitating success in meeting a national mitigation obligation when a large degree of heterogeneity exists amongst those engaging in the policy process.

To do so, using a linear public good game with a climate change framing, the experiment reported here examines whether groups of heterogeneous individuals can meet a collective emission-reduction target through individual contributions. Heterogeneity is introduced into the experiment by varying players' marginal productivity *to* the public good as well as their absolute returns to the private account, such that their relative, external marginal contribution cost is kept constant. In terms of the experiment framing, this means that players have different marginal abatement costs, meaning that it is cheaper for a particular player type to reduce an additional unit of emissions relative to another player type. The experiment consists of two games: a standard public good game and a communication game where participants are able to communicate with their group members in order to discuss how best to meet the target.

As previously mentioned, communication has been found (in an experimental setting) to be a useful conduit for improving contribution rates in public good games (Ledyard 1995). However, it is less clear whether this will still be the case when players have asymmetric

¹ Stakeholder participation in this context refers to government engagement with various groups of affected individuals in the design of policy. For example, active involvement of coal mining and the oil and gas industries, corporates, non-governmental and environmental organizations, and households in the design of a domestic climate change policy.

marginal abatement costs. In this instance, stakeholder engagement could be counterproductive by emphasising dissimilarities between players and amplifying disagreement.²

In this context, Reuben and Riedl (2013) note that the experimental evidence from public good games with symmetric players and sanctioning reflects the contribution norm of equal contributions, which, because players are symmetric, are all synonymous with the fairness principles of efficiency, equality and equity as applied to income.³ But in a setting where players are heterogeneous, these same principles can have markedly different implications for contribution behaviour, making it more difficult for players to reach consensus on a contribution norm (Reuben and Riedl 2013). For example, in a climate change context where individuals differ in terms of their marginal abatement costs (as is the case in the experiment reported here), should individuals with a low marginal cost of abatement (MCA) contribute more to mitigation (the public good) even though all individuals derive the same benefit from mitigation? In the laboratory setting, a player with a low MCA might well adopt the principle of equality as applied to mitigation. In this context, as both low and high-MCA types must reduce emissions equally, low-MCA types benefit by being able to generate the same emission reduction as high types through smaller contributions to the public good. Conversely, players with a high MCA might advocate for equality as applied to emissions. In this case, if low types are twice as productive in reducing emissions relative to high types, they will be responsible for reducing twice as many emissions. An additional layer of complexity in a climate change context arises from the notion of historical responsibility (reflecting the polluter-pays principle): specifically, does the fact that a particular player type is less responsible for the current stock of emissions in the atmosphere make them less responsible for public good provision? As such, with respect to the negotiation of domestic climate policy, heterogeneous stakeholder have an array of legitimate-sounding fairness principles from which to choose. In this context, several studies find evidence of a *self-serving bias* – whereby individuals' judgements of what is fair are aligned with their own self-interest (Babcock, Wang and Loewenstein 1996, Babcock and Loewenstein 1997, Babcock *et al.* 1997).

The results indicate that heterogeneity does diminish the impact of communication by making it harder for groups to reach consensus on a contribution strategy. Specifically, around 21% of

² Thanks to an anonymous reviewer for making this point.

³ For example, Fehr and Gächter (2000), Fehr and Gächter (2002) and Anderson and Putterman (2006) find that punishment increases as the differential between individual contributions and average group contributions widens.

groups were unable to reach agreement. Of those that did reach a consensus, there was overwhelming support for a contribution strategy that reflected the principle of equality of income (and which specified that all group members contribute their full endowment to mitigation (public account)).

Furthermore, with communication permitted between players, average contributions of both player-types increased significantly (relative to the baseline), as did the proportion of perfect co-operators (players contributing their full endowment to mitigation), suggesting that communication helps “high cooperators” to coordinate strategies (Gächter and Herrmann 2009). These results suggest that communication (and more broadly, stakeholder participation) is an important component of the policy-making process.

However, less encouragingly, while communication does improve cooperation, on average, it does not adequately facilitate public good provision. With the introduction of communication, two dominant contribution norms of free-riding and perfect cooperation emerge. In addition, while two thirds of groups agreed that all players should contribute their full endowment to mitigation, there was no instance where all group members actually complied with this agreement. The experimental design afforded participants a significant degree of anonymity (i.e. feedback on the individual contributions of group members was not provided) and it is likely that this anonymity coupled with non-binding nature of the group consensus accounts for the pervasive free riding evidence from both player types (and particularly players with a high-MCA). While the introduction of communication significantly increased the proportion of groups that met that target, from 35% in the baseline game to 50% with communication, in the context of meeting the mitigation target necessary to avoid a warming above 2°C, 50% compliance with the target is not sufficient to prevent catastrophic climate change.

Within a climate change setting, these combined results highlight the potential for communication as a mechanism to promote cooperation and the problems associated with non-binding agreements; and emphasise the need for stripping away of anonymity (for example through mandatory reporting) and for enhancing accountability (through fines for noncompliance).

The paper proceeds as follows: a literature review is provided in Section 2 while the rationale behind the framing of the experiment is discussed in Section 3. The experimental design and

procedures are outlined in Section 4 while the experimental results are described in Section 5. Finally, the paper concludes in Section 6.

2 Literature review

While the usual theoretical assumptions predict that non-binding communication will not deter free-riding, the experimental evidence suggests that communication within a *homogeneous* public good-game setting significantly improves cooperation (Gächter and Herrmann 2009, Ledyard 1995, Sally 1995, Ostrom *et al.* 1992, Ostrom 1998). Oprea *et al.* (2013) assess the impact of communication on continuous and discrete-time public good games using non-binding, chat-room-based communication. In both the discrete and continuous time settings, cooperation is modest at the outset and decays over time. With the introduction of communication, average contributions increase for both discrete and continuous treatments - but mean and median contribution rates are significantly higher in continuous time. As players in the continuous time interaction were able to constantly monitor each other's allocations and respond immediately, the authors argue that such responsiveness resolved the coordination problem.

However, as mentioned, if one considers stakeholder participation to be a real-world extension of communication in a laboratory setting, a key characteristic of stakeholder participation is that a large degree of heterogeneity exists amongst those engaging in the policy process.

In terms of voluntary public good provisions (without communication as a mechanism to improve cooperation) the evidence from public good games with homogenous players show that players make positive but suboptimal contributions to public good provision (Ledyard 1995, Cherry *et al.* 2005, Gächter and Herrmann 2009). In contrast, the effect of heterogeneity on cooperation is not fully clear from the literature. For example, while the effect of income heterogeneity on contributions has been examined via introducing endowment heterogeneity, the results of such studies are mixed with some authors finding endowment asymmetry increases cooperation (Chan *et al.* 1996, 1999; Buckley and Croson, 2006), and others concluding that cooperation is diminished (Anderson *et al.* 2008, Cherry *et al.* 2005). Palfrey and Prisbrey (1997) assign subjects different rates of return for their private accounts and find that the greater the return to the private good (and the higher the opportunity cost of public

contribution), the lower the cooperation rates. Fisher *et al.* (1995) examine heterogeneity by varying the marginal per capita return (MPCR) within groups.⁴ High types have a MPCR of 0.3 while low types have a MPCR of 0.75. While subjects were told not to assume that all participants have the same MPCR, they were not explicitly told that within-group MPCRs differed. The game was played in two ten-period sessions. Upon commencement of the second period, participants swapped player-type (with low types adopting the MPCR of high types and vice versa). While the descriptive statistics indicate that in both ten-year sessions, high-MPCR players contribute more to public good provision relative to low-MPCR players, these differentials are only significant in the second session. The authors conclude that contributions to the public good are strongly incentivised by the MPCR.

Additionally, the impact of communication on public good provision is less clear when heterogeneity is present. Using a linear public good game, Isaac and Walker (1998) find non-binding communication to increase voluntary contributions significantly when players have symmetric and asymmetric endowments (relative to a no-communication-symmetric-endowment treatment). However, contribution levels are significantly higher when players have symmetric endowments (relative to asymmetric endowments). The authors conclude that the efficiency of communication decreases as choice environments become more complex (for example through introducing asymmetry, varying information provision and increasing group size).

A number of studies examine the impact of sanctioning and communication in a heterogeneous setting by varying the MPCR (Reuben and Riedl 2009, 2013) or the marginal productivity to the public good (Tan 2008, Noussair and Tan 2011, Fellner *et al.* 2011).

Reuben and Riedl (2009) examine the impact of sanctioning when heterogeneity is present. Participants are in “privileged groups” where one player has a MPCR of 1.5 and a dominant strategy of contributing his full endowment while the remaining players have a MPCR of 0.5 (with the usual dominant strategy of free riding). The authors find that in the absence of punishment opportunities, there is significant underprovision of the public good in privileged groups – although when compared to normal groups, average contributions in privileged

⁴ The ratio between the marginal value of an experimental currency unit invested in the public account and the private account.

groups are significantly higher. While average contributions in both privileged and normal groups increase with the introduction of sanctioning, punishment is less effective in a privileged group setting. Specifically, relative to normal groups, contributions of low-benefit members in privileged groups are less responsive to punishment. Reuben and Riedl (2013) introduce heterogeneity by varying (in different treatments): (i) players' endowments, maximum permissible contribution and MPCR. In the absence of punishment, differentials in the contributions of different player types (across all groups) are small and diminish over time, with free-riding by both player types emerging as the dominant contribution behaviour. With the introduction of punishment, average contributions of both player types increase in all groups. In addition, contributions differ markedly across group types. The authors find that different kinds of heterogeneity are associated with different contributions norms – with the most normatively appealing contribution rules seemingly being the efficiency rule, equal contributions rule and a rule denoting that contributions be proportional to endowment.

Tan (2008) examines the impact of productive heterogeneity on cooperation. In the asymmetric treatment, players benefit equally from mitigation but the contributions of high types generate higher returns than the contributions of low types. In the absence of punishment, the author finds average group contributions to be significantly lower when heterogeneity is present (relative to a homogeneous control group) amid dramatic free-riding among low types coupled with insufficient contributions from high types (the results of the experiment reported here support this finding). However, average contribution rates of high types are found to be significantly higher than that of low types. Average contribution levels increase with the introduction of punishment. Furthermore, high productivity players are punished the most and also respond more actively to that punishment – implying a general consensus around a social norm dictating that high-productivity types bear more responsibility for fostering cooperation. Noussair and Tan (2011) similarly consider the impact of productive heterogeneity on cooperation. Players vote at regular intervals to punish below-average and/or above-average contributors of each player-type. While the institution enabling the punishment of below-average contributors, regardless of type, is the most efficient (as measured in the metrics of contributions and earnings), the authors find that groups seldom enact this institution as participants veto punishment institutions that sanction their type. Consequently inefficient regimes, if any, are established under heterogeneity.

Fellner *et al.* (2011) examine the role of information provision on contribution patterns in a public-good-game setting with productive heterogeneity. Information provision is varied across treatments: in an initial treatment players are aware of their own type and of the nominal contributions of other players, in a subsequent treatment players are additionally made aware of the distribution of productivity types within their group and, in a final treatment, players are able to link contributions to productivity type. When information provision is incomplete and players can't link contributions to player type, low-productivity types contribute significantly more than high types. Conversely, under full information, when productivity type is linked to individual contribution, high types contribute significantly more than low types. The authors emphasise the importance of information structure when productive heterogeneity is present.

3 Framing

As previously mentioned, the experiment reported here considers whether groups of heterogeneous individuals can meet a collective emission-reduction target through individual contributions. While the emission-reduction target (as per the framing) is not binding in the games discussed in this paper, it is emphasised to participants. Zizzo (2010) discusses experimenter demand effects (EDEs) whereby subjects modify their behaviour in response to cues from the experimenter with regard to what is appropriate behaviour. We are not concerned about the confounding effects of EDEs in this design given that, in a climate change context, governmental bodies place explicit pressure on citizens to, amongst others, use less electricity, use public transport and recycle. By emphasising the emission reduction target, we are merely providing the same social cues as government, which is necessary given the framing of the experiment.

Various studies have shown that adding context (framing) to experimental instructions significantly alters the results (Eckel and Grossman 1996, Lieberman *et al.* 2004, Burnham *et al.* 2000).⁵ Eckel and Grossman (1996) argue that in order to introduce the social and

⁵ Eckel and Grossman (1996) use a double-anonymous dictator game but frame the instructions by replacing the anonymous recipient with a well-known charity. Altruistic giving is significantly increased. Lieberman *et al.* (2004) conduct a repeated public good game with undergraduate students and Israeli pilots. The game is labelled as the Wall Street Game for half the participants and the Community Game for the other half. Cooperation was significantly less in the Wall Street Game. In a 2-person trust game, Burnham *et al.* (2000) substitute either the word "partner" or "opponent" into the instructions. Across pooled data, the authors find partners are significantly more trusting than opponents.

psychological factors that affect economic decision making, abstraction needs to be abandoned, at least to some extent. Lowenstein (1999) argues that the external validity of experimental results can be enhanced when appropriate context is added. The previous studies are compared to a paper by Abbink and Schmidt (2006), who contrast context-free and in-context instructions in a bribery experiment, and find no significant difference between the two frames. The authors argue that as the neutral version of the experiment adequately conveys the essential features of a bribery situation, framing the instructions does not enhance the subjects' interpretation of the game.

However, in the real-world climate change context, individuals are extremely divided on who bears the responsibility of reducing emissions, which policy instruments would be most effective (carbon tax or emission trading scheme, for example) and who should bear the cost of mitigation (the consumer or producer). In addition, climate change discourses become extremely emotionally charged and clouded by issues of social and distributive justice. In the United States support for climate change legislation even has a political dimension, with the Democratic Party associated with being pro-climate legislation and Republicans perceived as opponents.

As a result, it is the contention of this paper that, unlike in the case of Abbink and Schmidt (2006), completely abstract terminology does not sufficiently encapsulate all the dimensions of the real-life context.⁶ While we do not claim that the framing successfully encapsulates all these dimensions, it does enable subjects to draw on their own subjective perceptions about climate mitigation when deciding on their contribution strategy.

As will be discussed, subjects are referred to in the instructions as capital (firms) and labour (households). Subjects are merely told that these classifications represent different sectors of society with different abatement costs. We do not make any judgements about capital or labour in the text – for example that capital is “dirty” and is responsible for a greater proportion of emissions relative to labour, or that, according to income and historical responsibility, capital

⁶ Note that this study does not consider the extent to which context affects behaviour. We are rather assuming that context does affect behaviour in a climate change setting and therefore include context in the experiment design.

should be responsible for the bulk of emission reduction. All the wording in the instructions, beyond the framing of reduction of an emissions inventory, is neutral.⁷

4 Experiment

The experiment was conducted with 204 students recruited from the University of Cape Town in South Africa. On average, subjects were 21 years old and over 60% were male. Students from a broad spectrum of faculties, including commerce, humanities and the built environment, were targeted for participation. Sample statistics are provided in Appendix B.

Thirty-four groups of four students each participated in a series of one-shot linear public good games. As mentioned, the public good games were framed in terms of climate change mitigation and subjects allocated their endowment of 10 experimental currency units (ECUs) between mitigation (public account) and business-as-usual (private account). While participants were urged to meet a national emission reduction target, this target was not binding in the games discussed in this article.

Heterogeneity was introduced by varying players' marginal abatement costs. Within each group, two players were allocated a low MCA (high-productivity types) and two players are allocated a high MCA (low-productivity types). In terms of the framing, low-MCA players were told to think of themselves as representing capital (and in particular firms) while high-MCA players were framed in terms of labour (and in particular as households). Throughout the paper, these two player types are hereafter referred to as low and high-MCA players. The reader is referred to Appendix C where the instructions are reproduced.

⁷ What emerges is that subjects have clear attitudes about climate change (Appendix A). Specifically, 77% of subjects feel that firms *should definitely* be obligated to meet emission reduction targets, while only 15% feel that households *should definitely* be obligated to meet emission reduction targets.

The payoff functions for both the low-MCA player (π_l) and high-MCA player (π_h) are provided below:

$$\pi_{l_i} = 12(10 - c_{l_i}) + 0.25(20 \times \sum_{i=1}^2 c_{l_i} + 10 \times \sum_{i=1}^2 c_{h_i}) \quad (1)$$

$$\pi_{h_i} = 6(10 - c_{h_i}) + 0.25(20 \times \sum_{i=1}^2 c_{l_i} + 10 \times \sum_{i=1}^2 c_{h_i}) \quad (2)$$

where c_l and c_h signify investments in mitigation (the public account) by low-MCA and high-MCA players, respectively.

A player with a low marginal abatement cost is able to reduce more emissions with one ECU relative to a player with a high MCA. This is reflected in the players' payoff functions as asymmetric marginal contributions to the public account (productive heterogeneity has been introduced) (Tan 2008). Specifically, every ECU contributed towards mitigation (public account) by low and high-MCA players is multiplied by a factor of 20 and 10, respectively (equations 1 and 2).⁸ The accumulated total of ECUs in the public account (after being multiplied by the relevant factor of 20 and/or 10) denotes the emission reduction of the group. Appendix D denotes emissions reductions, by player type, per ECU allocated to mitigation (public good).

Participants are told that government has set a *national emission reduction target* of 240 units. This target can be met through low and high-MCA player-types contributing different combinations of ECUs to the public account (Appendix D). Note that although players are urged to meet the target, the target is not binding in the baseline and communication games. As will be discussed in the following sub-section, the target becomes binding in two tax games which are not discussed here.⁹ More broadly, in terms of the framing, as South Africa is party

⁸ Households have limited avenues with which to achieve significant reductions in electricity consumption; specifically, households can purchase solar water heaters, geyser blankets, replace incandescent light bulbs with more efficient Compact Fluorescent Light bulbs (CFLs), and reduce heating requirements by improving insulation. While expensive for the average household, many of these measures are prohibitively expensive for low-income households. Conversely, in addition to the above measures, the commercial sector can take advantage of "low hanging fruit" (decommission lifts and revolving doors, use timers to switch off lights in buildings and parking lots etc.). It is therefore assumed that capital has a lower marginal cost of abatement relative to labour, and is able to reduce more emissions with one ECU.

⁹ In the first tax scenario, both player types must reduce emissions equally, irrespective of the difference in the cost of abatement. As such, all four players (in a group) must reduce emissions by 60 units each. In the second tax scenario,

to the United Nations climate change convention, specifying a particular target is equivalent to Government agreeing to a specific quantifiable mitigation obligation under the Copenhagen Accord and then engaging stakeholders around this target.

Players earn a return from investing in mitigation (public account). On a global scale, given the assumption that a country's national abatement target forms part of a multilateral commitment (such as the Kyoto Protocol), returns to mitigation quantify the benefits of reduced likelihood of dangerous climate change (such as an extreme weather event). On a national scale, the returns quantify reduced pressure on the grid as mitigation is translated into a reduction in electricity usage. As everyone benefits equally from mitigation and no one is excluded from these benefits, the accumulated total of ECUs in the public account is distributed equally among the four group members – irrespective of individual contribution. As such, one ECU invested in mitigation by a low-MCA player generates a return, for each group member, of five ECUs; similarly, one ECU invested in mitigation by a high-MCA player generates a return, for each group member, of 2.5 ECUs.

In terms of the framing, participants were told that the private account represents investment opportunities other than mitigation. Since capital (low-MCA players) can more easily invest in productive (income-generating) activities, as compared to labour, capital generates a higher return from money invested in the private account. As such, each ECU contributed by low-MCA players (capital) to the private account generates a return of 12 ECUs as compared to a return of 6 for high-MCA players (labour) (equations 1 and 2). As such, the marginal per capita return, which is the ratio between the marginal value of an ECU invested in the public account and the marginal value of an ECU invested in the private account, is 0.42, the same for both player types, again indicating that everyone derives the same benefits from mitigation.

As evident from equations (1) and (2) and the preceding discussion, there are two sources of heterogeneity. Specifically, heterogeneity is introduced into the design by varying players' marginal productivity to the public good as well as their absolute returns to the private account. Despite this fact, the social dilemma structure of the game remains intact: specifically, for both

both player-types can reduce emissions by different quantities as long as they contribute the same amount in ECUs. If each player contributes four ECUs, each group will collectively meet the emission reduction target but low-MCA players will be reducing emissions by 80 units each, while high-MCA players will be reducing emissions by 40 units each.

player types, the return to allocating an ECU to the private account is greater than the return from allocating an ECU to the public account ($MPCR < 1$) ensuring that the dominant strategy is to contribute zero ECUs (Goeree et al. (2002). While the incentive structure of the game remains intact by keeping the MPCR constant (at 0.42 for both player types), we wanted the framing to be consistent with the external context that these different types of players or firms would normally face with regards to the climate change dilemma – hence the differences in returns to private investment and also the differences in marginal abatement costs.

Goeree et al. (2002) denote the differential between the return on the public account (internal return) and the return on the private account as the “net cost of contribution”. While player’s MPCR don’t differ, their net cost of contributions do differ: high-MCA players have a net cost of contribution of 3.5 while low-MCA players have a net cost of contribution of 7. While it is possible this differential might impact on players’ contribution decisions, from the chat transcripts (to be discussed later in this article) it is evident that players are almost exclusively focused on the MCA component of the design and on productive heterogeneity in terms of contributions to the public account. As such, the discussion through the text focuses around the impact of the heterogeneity of marginal abatement costs.

The *communication* game is identical to the baseline game except that, before contributing to the public account, group members are allowed to participate in costless online communication in order to discuss, as a group, how best to meet the target. However, prior to the commencement of the chat, players were informed that the group decision was not binding, and that they remained free to make their own contribution decisions.

4.1 Procedures

The experiment treatments are outlined in table 1. Treatment 1 (T1) consists of the baseline games and acts as a control. Treatments 2 and 3 (T2 and T3) consist of baseline, communication and tax games, and differ only in the ordering of the games.

Note that this article reports the results of the baseline and communication games only.¹⁰

¹⁰ In T2 and T3, once games 1 – 4 were *concluded*, subjects were asked to vote on which game they would like to play again as the final game for the day. Results from this voting game are not included in this analysis.

Table 1. Experiment summary

Games	Treatment 1		Treatment 2		Treatment 3	
	Session 1 <i>n</i> =36	Session 2 <i>n</i> =32	Session 1 <i>n</i> =32	Session 2 <i>n</i> =36	Session 1 <i>n</i> =36	Session 2 <i>n</i> =32
1	Baseline ₁	Baseline ₁	Baseline	Baseline	Baseline	Baseline
2	Baseline ₂	Baseline ₂	Comm.	Comm.	Tax44	Tax44
3	Baseline ₃	Baseline ₃	Tax36	Tax36	Tax36	Tax36
4	Baseline ₄	Baseline ₄	Tax44	Tax44	Comm.	Comm.

Note:

- Only the Baseline and Communication games are relevant to this study
- Each *treatment* was repeated on two separate days with different participants on each day (in the table this is referred to as *Session 1* and *Session 2*)
- No individual participated in more than 1 session

Participants were recruited through: an advertisement emailed to students and posted on various student networking sites, word of mouth, and announcements in lecture theatres. Upon entering the lab, participants were randomly allocated an experiment number and player type (low or high-MCA type). Participants were provided a R20 show-up fee and an ECU/ZAR exchange rate was specified in advance.¹¹

The experiments were conducted over a period of a week. As is evident from table 1, each of the three treatments were repeated over two days (referred to in the table as Session 1 and Session 2), with different participants in each day/session. Each treatment lasted approximately 2-3 hours (including payment). Participants were given four envelopes, each containing a summary sheet and set of instructions for the first four games.¹² The instructions were read aloud by the same enumerator over the week.

Throughout all the games, players were aware of the payoff functions of both player types as well as of the distribution of types within their group. Given the climate change framing, subjects were not provided any feedback information regarding the contribution behaviour of their group members, the rationale being that, in a real-world setting, emission reduction totals are often estimates, there is a lag between mitigation activities and reporting by authorities and, in many instances, reporting is voluntary as opposed to mandatory (as is currently the case in South Africa). Additionally, participants were not provided any feedback regarding their payoffs.

¹¹ ECU/ZAR = 0.25

¹² A new envelope was opened at the start of each new game.

In addition to a number of worked examples, participants were provided with a payoff table reflecting the payoff for each player type given their contributions and the contributions of the other players. Finally, *Excel*-based calculators reflecting the payoffs for each player-type were made available to the participants in an effort to lighten their cognitive load.

At the end of each game, subjects would enter their contribution on a decision sheet. These were collected by invigilators so that the enumerator could calculate the group's total contribution and thus each individual's earnings.

In all games discussed here, groups were reassigned after each game so that no person was in the same group twice.

During the communication game, players were able to communicate with their group members via an online chat programme. For the duration of the chat, players were provided with pseudonyms and individual identities remained anonymous. The chat sessions lasted approximately 20 minutes. While the chat sessions were monitored to prevent inappropriate language, no further restrictions were placed on participants. The communication game was the only game in which participants were able to interact with one another.

Anticipating that multiple contribution strategies could be proposed by the different members of the group and that a group might not necessarily reach consensus during the discussion, towards the end of the chat session the group members informally voted on which contribution strategy to adopt. For groups that had reached consensus during the chat, this vote simply amounted to a confirmation of the chosen contribution strategy. For groups that had not agreed on a contribution strategy, the vote provided a last opportunity for the players to reach consensus. However, even if the group reached agreement during the discussion and vote, players were informed that the group decision was not binding, and that they remained free to make their own contribution decisions. Information around the proportion of groups that reached consensus and the proposed contribution strategies is provided in Section 5.5. Groups that failed to reach consensus on a strategy continued to play the game as usual.

Finally, once all the games were completed, participants answered a short questionnaire that captured their demographic information and attempted to gauge attitudes towards climate change (some of these attitudes are reflected in Appendix A).

While the experiment had a climate change framing, the instructions were neutrally-worded in relation to issues around distributive justice; ideas such as equity, equality and fairness were never referenced.

5 Results

Mann-Whitney tests confirm there to be no significant difference in the distribution of the baseline and communication experiments in session 1 versus 2 of treatment 2 (baseline: $p = 0.9751$, communication: $p = 0.6887$) and session 1 versus 2 of treatment 3 (baseline: $p = 0.1306$, communication: $p = 0.1600$). As such, sessions are pooled across treatments. Furthermore, baseline and communication games in treatments 2 and 3 are also pooled (Mann-Whitney tests: baseline: $p = 0.1624$ and communication: $p = 0.1273$).

5.1 Average contributions

Average contributions for the (pooled) baseline and communication games are reflected in table 2.

Observation 1: Participants make voluntary but suboptimal contributions to public good provision

Observation 2: Contributions do not significantly differ by player-type

Climate change epitomises the public good dilemma of acting in ones' own interest versus acting in the interest of the collective. While the dominant strategy in a linear public good game is for each player to free-ride, as evident from table 2, average contributions as a percentage of endowment (across both player-types) range between 22% and 29% in the four baseline games in treatment 1, and are 32% in the baseline game in treatments 2 & 3 (pooled). These contributions are consistent with evidence from empirical data which suggest that people make positive but suboptimal contributions to public good provision (Ledyard 1995, Cherry *et al.*

2005, Gächter and Herrmann 2009). In a climate change setting, instances of voluntary (but suboptimal) mitigation are evident at the individual level, where people voluntarily reduce energy consumption, invest in energy saving technologies (such as solar panels and solar water heaters) and support producers who have taken steps to reduce their carbon footprint.

However, the contribution levels in the baseline games reflected in table 2 are lower than those found in the literature, where contributions to public good provision in one-shot public good games typically average between 40% and 60% of endowments. The low contribution rates revealed by this experiment are likely driven by the high return from investing in business-as-usual (private account) relative to investing in mitigation (public account). The experimental evidence shows that contributions are higher the more attractive the marginal return from investing in the public account (Gächter and Herrmann 2009). In the design of this experiment, an ECU invested in mitigation by a low-MCA player (high-MCA player) generates a return of 5 (2.5) ECUs relative to a return of 12 (6) for an ECU invested in the private account (equations 1 and 2). This conflict epitomises the climate change dilemma where *individual* returns on mitigation, particularly in the short term, are extremely low.

Table 2. Average contributions

	Treatment 1				Treatment 2 & 3 (pooled)		
	Avg. <i>n</i> =68	Low- MCA <i>n</i> =34	High- MCA <i>n</i> =34		Avg. <i>n</i> =136	Low- MCA <i>n</i> =68	High- MCA <i>n</i> =68
Baseline 1	2.90 (2.93)	2.68 (2.73)	3.12 (3.14)	Baseline	3.21 (2.90)	3.43 (2.84)	2.99 (2.96)
Baseline 2	2.32 (2.85)	1.79 (2.59)	2.85 (3.03)	Comm.	4.44 (4.23)	4.75 (4.08)	4.13 (4.38)
Baseline 3	2.18 (2.78)	2.26 (2.55)	2.09 (3.03)				
Baseline 4	2.35 (2.76)	2.38 (2.90)	2.32 (2.66)				

Notes:

- Participants are provided with an endowment of ten ECUs at the start of each game
- See Appendix E for average contributions for treatments 2 and 3 separately.

When comparing average contribution rates, Mann-Whitney tests reveal there to be no significant difference between the contributions of capital and labour in the four baseline games in treatment 1 as well as the baseline game in treatments 2 & 3 (pooled) ($p > 0.080$ for all games). The implication is that investment in mitigation does not differ according to productive heterogeneity. Reuben and Riedl (2013) similarly find that, in the absence of punishment

opportunities, heterogeneity is not relevant and, furthermore, that the dominant contribution norm is that of free-riding.

5.2 The distribution of contributions to mitigation

Observation 3: Free-riding is the dominant contribution norm for both player-types

An examination of individual contribution rates reveals that the dominant contribution strategy for both players is to free-ride (contribute nothing towards public good provision).

Table 3 depicts the frequency of contributions of between zero and ten ECUs to public good provision for the baseline games in treatment 1 and treatments 2 & 3 (pooled).

It is apparent from the table that free-riding is the dominant contribution strategy for both player types: in all the baseline games, binomial tests indicate that the proportion of contributions of zero ECUs significantly differs from the proportion of contributions at all other contribution levels at the 5% level.¹³

Table 3. Frequency distribution of contributions to the public good in the baseline games

	Contribution										
	0	1	2	3	4	5	6	7	8	9	10
Treatment 1											
<i>Low-MCA player type (n=34)</i>											
Baseline 1	0.324	0.029	0.177	0.206	0.059	0.088	0.000	0.029	0.029	0.029	0.029
Baseline 2	0.529	0.118	0.059	0.059	0.088	0.000	0.088	0.000	0.029	0.029	0.000
Baseline 3	0.353	0.147	0.147	0.118	0.029	0.059	0.029	0.059	0.059	0.000	0.000
Baseline 4	0.382	0.147	0.088	0.118	0.059	0.059	0.059	0.000	0.029	0.000	0.059
<i>High-MCA player type (n=34)</i>											
Baseline 1	0.294	0.088	0.118	0.088	0.177	0.059	0.029	0.000	0.059	0.000	0.088
Baseline 2	0.324	0.088	0.147	0.059	0.147	0.059	0.088	0.000	0.000	0.000	0.088
Baseline 3	0.500	0.088	0.177	0.000	0.029	0.029	0.029	0.088	0.000	0.000	0.059
Baseline 4	0.353	0.177	0.088	0.118	0.059	0.029	0.088	0.059	0.000	0.000	0.029
Treatment 2 & 3 (pooled)											
<i>Low-MCA player type (n=34)</i>											
Baseline	0.206	0.103	0.059	0.191	0.162	0.074	0.059	0.029	0.059	0.000	0.059
<i>High-MCA player type (n=34)</i>											
Baseline	0.338	0.074	0.088	0.059	0.132	0.132	0.074	0.015	0.029	0.000	0.059

¹³ With the exception of Baseline 1 in treatment 1 for the low-MCA player, where the proportion of contributions of zero ECUs (0.324) significantly differs from the proportion of contributions of 3 ECUs (0.206) at the 10% level.

The results from the baseline games indicate that, while there is a degree of voluntary cooperation, there is a significant amount of free-riding. Likewise, in a climate change context, not all developed and large emerging economies are signatories to the Kyoto Protocol and, on a domestic level, not all individuals take steps to reduce their carbon footprints. As communication has been shown significantly to improve cooperation in homogeneous public good games, the opportunity for communication is introduced.

5.3 Average contributions (treatments 2 & 3 pooled)

Observation 4: Communication significantly improves average contributions

With communication, average contributions of low-MCA players increased to 47.5% of endowment as compared to 41.3% for high-MCA player-types (table 2). Relative to the baseline game, average contributions increased significantly for both player-types with the introduction of communication (Wilcoxon signed-rank tests: Average: $p = 0.001$; capital: $p = 0.018$; labour: $p = 0.034$). In addition, average contributions of the two player-types do not differ significantly with communication (Mann-Whitney test: $p=0.184$), once again implying that investment in mitigation does not differ according to productive heterogeneity.

The impact of communication on contributions to the public good (mitigation) is also examined via OLS regression using the pooled data from the baseline and communication games in treatments 2 & 3 (table 4). Dummy variables for experimental treatment (*treatment 2 relative to 3*) and session, player type (*low-MCA type*) and game (*communication relative to baseline*) are included in the model. In addition variables reflecting participants' demographics (*gender and age*) as well as their attitudes towards climate change are included in the model. The climate change attitudinal variables are dummy variables relating to whether participants think greenhouse gases have a large (as opposed to partial) effect on global warming (*GHGs*), whether human activities are largely (as opposed to partially) responsible for climate change (*Human*) and, finally, whether South Africa should definitely/probably adopt quantifiable emission reduction targets (as opposed to probably or definitely not) (*Climate policy*). Equations 2 - 4 in table 4 are random effects panel data regressions. The dependent variable is participants' contributions in the relevant game.

Table 4. Contributions to the public good, by game and player type, treatments 2 & 3 (pooled)

<i>Dep. variable: Contribution level</i>					
Variables	(1) <i>(Baseline)</i>	(2) <i>(Baseline & Comm.)</i>	(3) <i>(Baseline & Comm.) (Low-MCA players)</i>	(4) <i>(Baseline & Comm.) (High-MCA players)</i>	(5) <i>(Comm.)</i>
Treatment	-0.796 (0.487)	-0.950 (0.529)	-1.882** (0.714)	-0.161 (0.753)	-1.107 (0.755)
Session	-0.564 (0.480)	-0.493 (0.518)	-1.389* (0.673)	0.249 (0.776)	-0.416 (0.736)
Low-MCA player	0.0604 (0.509)				0.305 (0.750)
Communication		1.250** (0.328)	1.338** (0.454)	1.164* (0.489)	
Female	0.344 (0.474)	0.110 (0.529)	0.500 (0.687)	0.0109 (0.785)	-0.122 (0.758)
Age < 20	-0.211 (0.474)	0.369 (0.522)	0.634 (0.707)	0.125 (0.765)	0.981 (0.763)
GHGs	-0.908 (0.683)	-0.631 (0.673)	-0.0480 (0.805)	-1.110 (1.063)	-0.318 (0.910)
Human	-0.310 (0.554)	-0.338 (0.641)	0.143 (0.812)	-0.949 (1.007)	-0.344 (0.918)
Climate policy	2.052** (0.628)	2.811** (0.786)	4.285** (1.059)	3.142** (1.052)	3.434* (1.332)
Constant	3.250** (0.867)	2.194 (1.141)	1.586 (1.047)	1.321 (1.752)	2.276 (1.842)
Prob > F/ Wald chi2	0.008	0.000	0.0000	0.068	0.122

Notes: Standard errors are adjusted for clustering; * and ** indicate significance at the 5% and 1% level, respectively.

Regression 2 confirms that average contributions are significantly higher in the communication game. Regression 3 confirms that contributions of players with low abatement costs significantly increase with communication. While Regression 4 indicates that high-MCA player-types significantly increased average contributions after communication, the *p*-value associated with the Wald chi-square statistic indicates that the null hypothesis that all model coefficients are zero can only be rejected at the 10% level. Regression 1 and 5 indicate that contributions do not differ significantly by player-type in both the baseline and communication experiments.¹⁴ Finally, indicating that the climate change framing does matter, there appears

¹⁴ To control for possible ordering effects, a dummy variable for both *treatment* and *session* have been included in the regression analysis (table 4). As ordering effects are evident in regression 3, for low-MCA player types, auxiliary regressions were run for treatments 2 and 3 separately (see results in appendix F). While auxiliary regression 1 suggests that contributions of low-MCA players do not increase significantly with communication in treatment 2, communication is synonymous with greater cooperation in treatment 3 (auxiliary regression 2). To further test for ordering effects, the analysis is replicated for both treatments 2 and 3 separately. Broadly, the results of the paper remain unchanged. Specifically: (i) free-riding among both player-types is pervasive in both the baseline and communication games in both treatments, (ii) when communication is introduced, contributions

to be a general result whereby individuals that support South Africa adopting quantifiable emission reduction targets are more cooperative within the game. In terms of magnitude of result, this positive attitudinal variable has a larger effect on contribution than the provision of communication.

5.4 The distribution of contributions to emissions (treatments 2 & 3 pooled)

Observation 5: Contributions are polarised between free-riding and perfect cooperation

Observation 6: Players with high marginal abatement costs are more likely to free-ride

Table 5 reflects the frequency of contributions to mitigation (public good) for the pooled baseline and communication games by player-type.

As is evident from table 5, the frequency of free-riding (contributing zero ECUs) increases with the introduction of communication. Specifically, the proportion of capital free-riders increases from 20.6% in the baseline game to 26.4% with communication, although this increase is not significant (McNemar Chi-square test: $p = 0.248$). The proportion of labour players free-riding increases significantly from 33.8% in the baseline game to 45.6% with communication (McNemar Chi-square test: $p = 0.033$). The tendency to free-ride generally persists across treatments with approximately 71% of capital players and 87% of labour players who free-ride in the baseline game continuing to free-ride with the introduction of communication.

Finally, labour players free-ride with greater frequency relative to capital players in both the baseline and communication games (although this result is only significant in the communication game) (Chi-square tests: Baseline: $p = 0.083$; Communication: $p = 0.020$). This result suggests that high-MCA players under-contribute to the public good relative to their capital counterparts with a lower marginal cost.

are polarized between free-riding and perfect cooperation, (iii) the frequency of perfect cooperation increases significantly for both player-types with communication and (iv) public good provision (in terms of the proportion of groups meeting the target) increases with communication. In addition, the chat transcripts indicate there to be no significant difference in subjects' negotiation attitudes in treatments 2 and 3. In both treatments, the majority of groups agreed on a strategy whereby everyone contributes their full endowment to mitigation.

Table 5. Frequency distributions of contributions – treatments 2 & 3 (pooled)

Game	Contribution (ECUs)										
	0	1	2	3	4	5	6	7	8	9	10
<i>Average (n=136)</i>											
Baseline	0.272	0.088	0.073	0.125	0.147	0.103	0.066	0.022	0.044	0.000	0.059
Comm.	0.360	0.037	0.052	0.037	0.059	0.059	0.037	0.029	0.022	0.029	0.279
<i>Low-MCA players (n=68)</i>											
Baseline	0.206	0.103	0.059	0.191	0.162	0.074	0.059	0.029	0.059	0.00	0.059
Comm.	0.264	0.044	0.074	0.074	0.074	0.088	0.029	0.029	0.000	0.015	0.309
<i>High-MCA players (n=68)</i>											
Baseline	0.338	0.074	0.088	0.059	0.132	0.132	0.074	0.014	0.029	0.00	0.059
Comm.	0.456	0.029	0.029	0.000	0.044	0.029	0.044	0.029	0.044	0.044	0.250

Players who contribute their full endowment to mitigation (public good) are referred to as perfect co-operators. The percentage of capital players contributing 10 ECUs to the public good increased significantly from 5.9% in the baseline phase to 30.9% with communication (McNemar Chi-square test: $p = 0.000$). Labour players also shows a marked increase in cooperation with the introduction of communication – with the proportion of perfect co-operators increasing significantly from 5.9% to 25% (MacNemar Chi-square test: $p = 0.002$).

Testing the relationship between player-type and perfect cooperation does not yield a statistically significant association in either the baseline or communication games (Chi-square tests: Baseline: $p = 1.000$; Communication: $p = 0.445$). This means that the propensity to contribute one's full endowment to public good provision is independent of player-type.

As is evident from table 5, contributions are polarised between free-riding and perfect cooperation. In the baseline game, 26.5% of capital players contribute *either 0 or 10* ECUS to the public good. This proportion increases to 57.3% with communication. Likewise, the proportion of labour players contributing *either 0 or 10* ECUs increases from 39.7% in the baseline to 70.6% in the communication game.

The impact of communication and player-type on contributions to the public good (mitigation) is further examined using a hurdle model, the results of which are reported in table 6. Once again the dependent variable is participants' contributions in the relevant game. The explanatory variables are familiar from table 4. Following Cameron and Trivedi (2010) and Garcia (2013), it is assumed that the decision to cooperate (contribute to the public good of mitigation) is made in two steps, reflecting a two-stage decision-making process. Firstly, a

subject decides whether s/he wants to contribute or free-ride (the participation decision) and, secondly, determines the optimal contribution amount (quantity decision) assuming the decision to not free ride. The participation outcome (zero vs. positive) is modelled using logistic regression while the quantity outcome is modelled using a zero-truncated negative binomial regression. The corner solution in this context is zero given that free-riders will contribute zero tokens and contributions to the public good can't be negative.

With respect to the interpretation of the results, a positive coefficient in panel A (logit model) indicates that the given regressor increases the probability of a positive observation (not free riding); in panel B, a positively signed coefficient indicates that, conditional on not free-riding, the regressor increases the level of contribution (Cameron and Trivedi 2010). The results of the hurdle model echo the preliminary discussion.

The results from panel A indicate that, in the communication treatment (regression 5), low-MCA players are more likely to contribute positively to the public good (and not free-ride) relative to high-MCA players. As evident from table 5, 26% of low-MCA players contributed zero ECUs in the pooled communication game, significantly less relative to 46% of high-MCA players (Chi-square test: $p = 0.020$). Furthermore, high-MCA players are more likely to free ride in the communication treatment relative to the baseline treatment (regression 4). Also reflected in table 5, the proportion of high-MCA players free-riding increases significantly from 33.8% in the baseline game to 45.6% with communication (McNemar Chi-square test: $p = 0.033$).

The results from panel B indicate that once the decision to contribute (and not free-ride) has been made, contributions are higher for both low and high-MCA players in the communication treatment relative to the baseline treatment (regressions 3 & 4). The descriptive statistics confirm this. More specifically, conditional on *not* contributing zero, low and high-MCA players contributed on average 4.3 and 4.5 ECUs in the baseline treatment, respectively. In contrast, again conditional on not contributing zero, low and high-MCA players contribute on average 6.5 and 7.6 ECUs in the communication treatment, respectively.

Table 6. Hurdle model estimates, treatments 2 & 3 (pooled)

Variables	(1) <i>(Baseline)</i>	(2) <i>(Baseline & Comm.)</i>	(3) <i>(Baseline & Comm.) (Low-MCA players)</i>	(4) <i>(Baseline & Comm.) (High-MCA players)</i>	(5) <i>(Comm.)</i>
<i>Panel A: Participation</i>					
Treatment	-0.147 (0.433)	-0.164 (0.803)	-0.624 (1.028)	0.404 (1.139)	-0.0763 (0.393)
Session	0.0709 (0.410)	-0.243 (0.768)	-1.114 (1.053)	0.746 (1.137)	-0.206 (0.379)
Low-MCA player	0.549 (0.413)				0.799* (0.378)
Communication		-1.002* (0.443)	-0.699 (0.623)	-1.300* (0.651)	
Female	0.982* (0.463)	1.340 (0.832)	0.836 (1.053)	2.228 (1.290)	0.339 (0.399)
Age < 20	0.0701 (0.412)	0.747 (0.792)	2.293 (1.247)	-0.291 (1.123)	0.589 (0.388)
GHGs	-0.576 (0.610)	-0.619 (1.005)	0.155 (1.291)	-0.939 (1.470)	0.0456 (0.501)
Human	-0.490 (0.518)	-0.523 (0.956)	0.726 (1.186)	-2.031 (1.621)	0.0761 (0.487)
Climate policy	0.825 (0.884)	2.277 (2.165)	3.965* (1.784)	2.618 (2.793)	0.689 (1.209)
Constant	0.366 (1.052)	0.688 (2.264)	-0.830 (1.530)	-0.443 (3.267)	-0.568 (1.357)
<i>Panel B: Quantity</i>					
Treatment	-0.246* (0.114)	-0.252** (0.093)	-0.429** (0.147)	-0.185 (0.106)	-0.274* (0.109)
Session	-0.205 (0.117)	-0.077 (0.087)	-0.228 (0.125)	0.031 (0.110)	0.003 (0.101)
Low-MCA player	-0.124 (0.113)				-0.241* (0.097)
Communication		0.487** (0.066)	0.436** (0.096)	0.541** (0.092)	
Female	-0.136 (0.114)	-0.121 (0.086)	0.080 (0.122)	-0.298* (0.123)	-0.125 (0.103)
Age < 20	-0.079 (0.120)	-0.015 (0.087)	-0.018 (0.131)	-0.004 (0.112)	0.000 (0.101)
GHGs	-0.065 (0.156)	-0.030 (0.117)	0.063 (0.167)	-0.052 (0.123)	-0.019 (0.135)
Human	-0.0042 (0.132)	-0.070 (0.105)	-0.064 (0.132)	-0.027 (0.145)	-0.109 (0.128)
Climate policy	0.735** (0.152)	0.831** (0.322)	0.634** (0.164)	0.939* (0.365)	1.086 (0.564)
Constant	1.339** (0.208)	0.984** (0.344)	1.257** (0.178)	0.815* (0.400)	1.258* (0.585)

Notes: Results reported as coefficients; Standard errors in parenthesis; Standard errors are adjusted for clustering at the individual level; * and ** indicate significance at the 5% and 1% level, respectively.

5.5 Consensus around contribution strategies

As previously mentioned, in a climate change setting where stakeholders engaging in the policy process are heterogeneous (for example in their marginal abatement costs), parties to the negotiations may struggle to reach consensus on a “fair” way to distribute the abatement burden. In this sense, stakeholder engagement could be counterproductive by emphasising dissimilarities between players and amplifying disagreement. In this context, in this section we examine whether participants were able to reach consensus on a contribution strategy and whether a generalisable notion of fairness emerged from the group discussions.

The following discussion on contribution rules is derived from Reuben and Riedl (2013) and Fellner *et al.* (2011) who distinguish between the *efficiency rule* and the *relative contribution rule*. Additional references are cited in the text.

The efficiency rule relates to maximising collective wellbeing and denotes that participants contribute their full endowment to the public good. The relative contribution rule defines a “fair contribution” as fair in relation to the contributions of others. Two fairness principles that reflect this rule are that of *equality* and *equity* (Konow 2003). Equality relates to the equalisation of outcomes (for example income or contributions) regardless of individual capacity whereas equity denotes a fair outcome to be one where the outcome is proportionate to individual capabilities. In the experiment reported here, the application of the principle of equality would render irrelevant the heterogeneity in marginal abatement costs of high and low-MCA players. Conversely, an application of the equity principle would account for the fact that low-MCA types are twice as productive as high types in reducing emissions.

An application of the equality principle to emissions reduction implies that high-MCA players contribute twice as much to mitigation as low-MCA players (in order to reduce emissions by the same quantity (Appendix D)). Conversely, the application of the equity principle to emissions reduction denotes that both player types contribute the same amount of ECUs to mitigation (in this case low-MCA players are reducing twice the amount of emissions as high types) (Appendix D). Due to the heterogeneity in the payoff functions of players, an application of equality to income implies that both player types contribute their full endowment to mitigation (in this case the social optimum is reached).

Table 7. Proportion of groups reaching consensus on a contribution strategy

No consensus (%)	Fairness principle (%)			
	Equality of income	Equity applied to emissions	Equality of emissions	Variant of equality of emissions
0.206	0.588 $C_h = C_l = 10$	0.147 $C_h = C_l$	0.029 $C_h = 2C_l$	0.029 $C_h = 1.67C_l$

Table 7 reflects the proportion of groups reaching consensus on a particular fairness strategy (if any). Around 21% of groups were unable to reach any consensus while nearly 60% of groups reached consensus on the principle of equality of income. In the context of the experimental design, equality of income denotes that all group members (irrespective of player type) contribute all ECUs to mitigation. Equality of income is thus also synonymous with efficiency as participants are maximising collective wellbeing by contributing their full endowment. The discussion in the chat sessions were primarily centred on the idea that the most “fair” strategy was one where everyone derived the same income, while efficiency was a secondary focus. Around 15% of groups agreed on a contribution strategy reflecting the principle of equity as applied to emissions. This strategy specifies equal contributions to public good provision (although contributions are less than full endowment). In terms of the framing, this means that low-MCA players are reducing twice the amount of emissions relative to high types. Finally, just less than 6% of groups reached consensus on a strategy of equality as applied to emissions (both types reduce emissions equally despite differences in marginal abatement costs). In this case, high-MCA contribute approximately twice the amount of ECUs to public good provision than that of low types.

As mentioned previously, regardless of whether a group reached consensus on a particular contribution strategy, the group consensus was not binding and players were free to decide their own contribution. Furthermore, as the results from the previous section indicated that contributions were polarised between free riding and perfect cooperation, it is evident that there was significant noncompliance in terms of participants acting in accordance with the group consensus. In particular, in this context of the agreements reached by groups during their online discussion, there was no instance where all four group members complied in terms of the contributions required by their group’s adopted contribution strategy (for example, despite 59% of groups agreeing that all players should contribute their full endowment to mitigation, there was no group where all four players contributed 10 ECUs in the communication game). It is

clear that even though groups were often successful in reaching consensus, the non-binding nature of the agreements and lack of enforcement mechanisms allowed players to deviate significantly from their agreements.

5.6 Meeting the emission reduction target

The introduction of communication facilitated greater success in reaching the emission reduction target. As evident from table 8, in T1, on average, only 18% of groups met the target in the four baseline phases. In T2 and T3 (pooled), 35% of groups met the target during the baseline phase. This increased significantly to 50% when participants were allowed to communicate with one another (McNemar test: $p = 0.0075$).

Table 8. Success in meeting the Emission Reduction Target

	<i>Group Emission Reduction Target: 240^l</i>					
	Treatment 1				Treatments 2 & 3	
	Baseline 1	Baseline 2	Baseline 3	Baseline 4	Baseline	Comm
% of groups that met the target	0.24	0.24	0.12	0.12	0.35	0.50
Average group emission reduction	169.4	128.8	132.4	141.8	196.8	272.6
No. of groups	17	17	17	17	34	34

In addition, while an emission reduction of 240 was urged, average group contributions in all the baseline games fall short of this target: average group contributions across the four baseline games in treatment 1 are 143.1, while the average group contribution in the pooled baseline game in treatments 2 and 3 is 196.8. Conversely, average group contributions in the pooled communication game at 272.6 exceed the target.

6 Discussion

While multilateral climate negotiations act as a mechanism for cooperation, they have failed to induce widespread participation. The experiment reported here considers whether cooperation is possible in such a climate change context. As heterogeneity is a crucial characteristic of climate talks, we use a public good game with a climate change framing to examine whether groups of heterogeneous individuals can meet a collective emission-reduction target through individual contributions. Subjects are able to communicate with one another in order to determine how to distribute the abatement burden between two different sectors of society.

The current model for tackling climate change is a top-down approach in terms of which emission reduction targets are negotiated at international climate talks and then implemented at a domestic-level. This implementation phase requires a diversity of groups, including businesses, rich and poor households, farmers, lobbyists, environmentalists and oil and mining companies, to work together to reduce emissions.

The experiment reported here considers the role of communication (and by extension, stakeholder participation) in facilitating success in meeting a national mitigation obligation when players are asymmetric. Stakeholder participation is increasingly seen as an important component of the formulation of policy responses to climate change (and more generally in natural resource management) (Few *et al.* 2006, Parkins and Mitchell 2005, Kasemir *et al.* 2003). Without incorporating the public's viewpoints, climate policy is likely to be stalled very early on in the implementation phase (Kasemir *et al.* 2003). Accordingly, our results show that communication (and by extension, stakeholder participation) plays a valuable role in helping players to coordinate mitigation strategies and subsequently reach the reduction target, even when those players are heterogeneous. As detailed earlier, players were urged to meet a national emission-reduction target of 240 units. Without the opportunity to communicate with group members, only 35% of groups (in treatments 2 and 3 (pooled)) were able to meet the target. When able to coordinate strategy via online communication, however, this proportion increased significantly to 50%. Furthermore, with the introduction of communication, average contributions of both low and high-MCA players increased significantly relative to the baseline game. Finally, the proportion of perfect co-operators of both player-types (players who contribute their full endowment to public good provision) also increased significantly with the introduction of communication (Low MCA-players: 30.9%, High MCA-players: 25%).

However, the results also illustrate the problem with non-binding, piecemeal agreements. There was significant noncompliance in terms of the group consensus: for example, while 65% of groups agreed that each member would contribute their full endowment to the public account, there was no group in which this actually happened. In actuality, there was no instance where all group members complied with the agreed contribution strategy. In addition, with the introduction of communication, the prevalence of free-riding increased significantly (by 11.8%) among high-MCA players. Furthermore, for both player types, cooperation was polarised between free-riding and perfect cooperation.

Fellner *et al.* (2011) illustrate the impact of information provision on cooperation – particularly in instances where individuals contributing to joint tasks have heterogeneous capacities (for example different marginal abatement costs). Information provision in this context relates to having feedback on the individual contributions of your group members. The authors illustrate that as one moves along the spectrum from incomplete information (no information of the distribution of types in your group) to complete information (where players can link contributions to player type), average contributions of both player types generally increase and high-productivity players contribute significantly more than low types. Tan (2008) who also provides feedback information to players and Fisher *et al.* (1995) (who alters the information structure by swapping players' MPCRs) similarly find that high types contribute significantly more than low types.

In the experiment reported here, players were aware of the payoff functions of both player types as well as of the distribution of types within their group, but, given the climate change framing and context, subjects were not provided any information regarding the contribution behaviour of their group members: the rationale for this being that in a real-world setting, emission reduction totals are often estimates, there is a lag between mitigation activities and reporting by authorities and institutions and reporting of emission reduction activities are often voluntary (as is the case currently in South Africa). In this context it is likely that the non-binding nature of the group consensus coupled with the extreme anonymity of players (i.e. no feedback on contribution behaviour was provided) underpinned (i) the significant degree of free-riding, (ii) non-compliance with the group decision and (iii) the finding that contributions do not differ by player type. Ultimately, in terms of policy relevance in a climate change context, the implication is that anonymity needs to be stripped away, for example through mandatory reporting. This is no doubt an area for future research.

Furthermore, within the context of the game, while the majority of groups were able to reach consensus (with a majority of groups agreeing to contribute their full endowment) free-riding was pervasive. These results indicate that while stakeholder participation is important in promoting cooperation, there is always the risk that free-riders will engage in participatory processes on the formulation of climate policy, but then thwart efforts at the implementation phase by reneging on an agreed-to mitigation obligation (the anonymity implicit in the design facilitated this). The implication is that punishment opportunities will likely play an important

role in compelling cooperation. In this context, a number of studies have shown that in a heterogeneous public good context, sanctioning improves cooperation (Reuben and Riedl 2009, Tan 2008, Noussair and Tan 2009). Relatedly, high-MCA players were found to free-ride significantly more than low types in the communication game. The implication is that the presence of heterogeneity – which is translated within the framework of the game as an inequality – provides individuals with a justification to renege on an agreement. In a climate change context, parties to the negotiations who view themselves as unfairly disadvantaged might be more prone to non-compliance. Participatory processes must thus take cognisance of the equity contexts within which the negotiations are happening (for example, equity is an important subtext in multilateral climate change negotiations).

Finally, while communication increased cooperation, the outcome was not sufficient. If one hypothesises that the specified target of 240 units was part of a multilateral climate treaty – the aim of which was to keep temperature warming below 2 degrees, the threshold for catastrophic climate change – if only 50% of the population met the target, catastrophic climate change would not have been subverted. Thus, while participatory processes play an important role in facilitating mitigation, such processes are not sufficient on their own.

References

- Abbink, K., Hennig-Schmidt, H., 2006. Neutral versus loaded instructions in a bribery experiment. *Experimental Economics*, 9: 103-121.
- Anderson, L. R., Meller, J. M., Milyo, J., 2008. Inequality and public good provision: an experimental analysis. *Journal of Socio-Economics*, 37 (3): 1010-1028.
- Anderson, C., Putterman, L. 2006. Do non-strategic sanctions obey the law of demand? The demand for punishment in the voluntary contribution mechanism. *Games and Economic Behaviour* 54:1 – 24.
- Babcock, L., Wang, X., Loewenstein, G. 1996. Choosing the Wrong Pond: Social Comparisons in Negotiations that Reflect a Self-Serving Bias. *The Quarterly Journal of Economics* 111(1): 1-19.
- Babcock, L., Loewenstein, G. 1997. Explaining Bargaining Impasse: The Role of Self-Serving Biases. *The Journal of Economic Perspectives* 11(1): 109-126.
- Babcock, L., Loewenstein, G., Issacharoff, S., Camerer, C. 1997. Biased Judgments of Fairness in Bargaining. *The American Economic Review* 85(5): 1337-1343.
- Brekke, K., Johansson-Stenman, O., 2008. The behavioural economics of climate change. *Oxford Review of Economic Policy*, 24(2): 280 – 297.
- Buckley, E., Croson, R., 2006. Income and wealth heterogeneity in the voluntary provision of linear public goods. *Journal of Public Economics*, 90(4-5): 935-955.
- Burnham, T., McCabe, K., Smith, V., 2000. Friend-or-for intentionality priming in an extensive form trust game. *Journal of Economic Behavior & Organization*, 43: 57-73.
- Cameron, C., Trivedi, P., 2010. *Microeconometrics Using Stata: Revised Edition*. StataCorp LP, College Station, Texas.

- Chan, K. S., Mestelman, S., Moir, R., Muller, R. A., 1996. The voluntary provision of public goods under varying income distributions. *The Canadian Journal of Economics*, 29 (1): 54-69.
- Chan, K. S., Mestelman, S., Moir, R. Muller, R. A., 1999. Heterogeneity and the voluntary provision of public goods. *Experimental Economics*, 2(1): 5-30.
- Cherry, T. Kroll, S., Shrogen, J., 2005. The impact of endowment heterogeneity and origin on public good contributions: evidence from the lab. *Journal of Economic Behaviour and Organization* , 57: 357-365.
- Eckel, C., Grossman, P., 1996. Altruism in Anonymous Dictator Games. *Game and Economic Behavior*, 16: 181-191.
- Fehr, E., Gächter, S. 2000. Cooperation and Punishment in Public Goods Experiments. *The American Economic Review* 90(4):980 – 994.
- Fehr, E., Gächter, S. 2002. Altruistic punishment in humans. *Nature* 415:137 – 140.
- Fellner, G., Iida, Y., Kröger, S., Seki, E. 2011. Heterogeneous productivity in voluntary public good provision: an experimental analysis. IZA Discussion Paper No. 5556, Institute for the Study of Labor (IZA).
- Few, R., Brown, K., Tompkins, E., Public participation and climate change adaptation, Tyndall Centre for Climate Change Research, Working Paper 95.
- Fisher, J., Isaac, R., Shatzberg, J., Walker, J., 1995. Heterogeneous demand for public goods: behavior in the voluntary contributions mechanism. *Public Choice*, 85(3): 249-266
- Gächter, S., Herrmann, B., 2009. Reciprocity, culture and human cooperation: previous insights and a new cross-cultural experiment. *Philosophical Transactions: Biological Sciences*, 364(1518): 791- 806.

- Garcia, B., 2013. Implementation of a double-hurdle model. *The Stata Journal*, 13(4): 776-794.
- Goeree, J., Holt, C., Laury, S., 2002. Private costs and public benefits: unravelling the effects of altruism and noisy behavior. *Journal of Public Economics*, 83: 255-276.
- Hasson, R., Löfgren, A., Visser, M., 2010. Climate change in a public goods game: Investment decision in mitigation versus adaptation. *Ecological Economics* 70: 331–338.
- Isaac, R., Walker, J., 1988. Communication and free-riding behaviour: the voluntary contribution mechanism. *Economic Inquiry*, Vol. XXVI, 585-608.
- Kasemir, B., Jaeger, C., Jäger, J., 2003. Citizen participation in sustainability assessments. In *Public Participation in Sustainability Science: A Handbook*, ed. Kasemir, B., Jäger, J., Jaeger, C., Gardner, M., page 3. Cambridge University Press.
- Konow, J., 2003. Which Is the Fairest One of All? A Positive Analysis of Justice Theories. *Journal of Economic Literature*, Vol. XLI: 1188–1239.
- Ledyard, J. O., 1995. Public goods: a survey of experimental research. *The Handbook of Experimental Economics*, 2: 111-194.
- Lieberman, V., Samuels, S., Ross, L., 2004. The name of the game: predictive power of reputations versus situational labels in determining prisoner's dilemma game moves. *Personality and Social Psychology Bulletin*, 30: 1175 – 1185.
- Loewenstein, G., 1999. Experimental economics from the vantage-point of behavioural economics. *The Economic Journal*, 109: 25-34.
- Noussair, C., Tan, F., 2011. Voting on punishment systems within a heterogeneous group. *Journal of Public Economic Theory*, 13(5): 661 - 693.
- Oprea, R., Charness, G., Friedman, D., 2013. Continuous time and communication in a public-goods experiment. Working paper.

- Ostrom, E., Walker, J., Gardner, R., 1992. Covenants with and without a sword: self-governance is possible. *The American Political Science Review*, 86(2): 404-417.
- Ostrom, E., 1998. A behavioural approach to the rational choice theory of collective action. *American Political Science Review*, 92: 1-22.
- Palfrey, T., Prisbrey, J., 1997. Anomalous behaviour in public goods experiments: how much and why? *The American Economic Review*, 87(5): 829-846.
- Parkins, J., Mitchell, R., 2005. Public participation as public debate: a deliberative turn in natural resource management. *Society and Natural Resources*, 18: 529–540.
- Ringius, L., Torvanger, A., Underdal, A. 2002. Burden Sharing and Fairness Principles in International Climate Policy. *International Environmental Agreements: Politics, Law and Economics* 2: 1-22.
- Reuben, E., Riedl, A., 2009. Public goods provision and sanctioning in privileged groups. *Journal of Conflict Resolution*, 53(1): 72-93.
- Reuben, E., Riedl, A., 2013. Enforcement of contribution norms in public good games with heterogeneous populations. *Games and Economic Behavior*, 77: 122-137.
- Sally, D., 1995. Conversation and cooperation in social dilemmas: A meta-analysis of experiments from 1958 to 1992. *Rationality and Society*: 7(1), 58.
- Tan, F., 2008. Punishment in a linear public good game with productivity heterogeneity. *De Economist*, 156(3): 269-293.
- Zizzo, D., 2010. Experimenter demand effects in economics experiments. *Experimental Economics*, 13: 75-98.

Appendix A. Sample statistics

Table A1. Attitudes towards climate change

	Subjects N=204
Do GHG emissions effect global warming?	
Yes, to a large extent	0.73
Yes, partially	0.25
No	0.02
Are human activities responsible for climate change?	
Yes, to a large extent	0.71
Yes, partially	0.27
No	0.01
Should the government be formulating a climate change policy which includes quantifiable emission reduction targets?	
Yes, definitely	0.59
Yes, probably	0.37
No, probably not	0.02
No, definitely not	0.02
Should firms be obligated to meet emission reduction targets?	
Yes, definitely	0.77
Yes, probably	0.19
No, probably not	0.04
No, definitely not	0.00
Should households be obligated to meet emission reduction targets?	
Yes, definitely	0.15
Yes, probably	0.36
No, probably not	0.38
No, definitely not	0.11

Appendix B. Sample statistics

Table B1. Sample statistics

	Subjects n=204
Gender	
Male	0.63
Female	0.37
Race	
Black	0.78
Coloured	0.07
Indian	0.05
White	0.07
Other	0.02
Schooling	
Public	0.65
Private	0.35
Nationality	
South African	0.69
Other	0.31
Age	20.92 (1.76)
Household size	5.56 (2.55)
Family's financial situation	
Upper income	0.05
Middle income	0.67
Lower income	0.28

Note: Standard deviations in parenthesis

Appendix C. Instructions (excerpt)

Baseline Game¹⁵

You are about to participate in an economics experiment that is part of a long term research project on how best to combat the negative effects of climate change.

The following pages contain the instructions, which we are going to go through now. You will need to make various decisions throughout the experiment so it is important to ensure that you understand the instructions. If at any point something is unclear to you please raise your hand and someone will respond. In addition to making various decisions during the course of the experiment, you will be required to answer some questions.

Please note that the researchers will not attempt to identify you with any of the decisions made or answers provided during the experiment or to name you as a participant in the study; nor will they facilitate anyone else's doing so. We have given each person an experiment number in order to ensure anonymity.

Unless told otherwise, communication with anybody except the experimenters is strictly prohibited.

The game is played in groups of four - thus it will be you and three other players in your group. Nobody except for the experimenters will know who is in which group. You will not learn the identity of the other three members of your group, neither during nor after the experiment. Please note that your **group members will change throughout the experiment: the experiment consists of various different parts and you will be randomly assigned to a new group at the start of each part.**

Players can represent either **Capital** or **Labour**. You can also think of this as players either representing firms (Capital) or households (Labour). We have handed out a piece of paper to all of you which specifies which factor of production you represent. Please take a look now.

Please note that your factor of production allocation will remain the same throughout the experiment.

Note that in each group of four: **two players will be representatives for Labour** and **two players will be representatives for Capital.**

Everyone in the group has the same initial wealth and is given the same information to help make their decisions.

¹⁵ The instructions refer to tokens while the text refers to ECUs. These terms are interchangeable.

Payment

Just for participating you will be paid R20. Depending on your decisions and the decisions of other players in your group, you may earn considerably more money. The amount you make will be paid to you at the end of this experiment **as a cash cheque, which you can exchange for cash at any ABSA bank.**

During the experiment we will not speak of Rands but rather of tokens. First your whole income will be calculated in tokens. At the end of the experiment, the whole amount you have earned in tokens will be converted to Rand at the following rate and paid out as a cash cheque:

1 token = R0.20

You will need to fill in and sign a receipt in order to receive your payment, but this information is strictly for UCT payment purposes and will not be used in the experiment.

Context

This experiment deals with how to distribute the burden of reducing harmful greenhouse gas emissions between different sectors of society.

For the purposes of this experiment we assume that the South African government **sets a national target for the reduction of emissions.**

You must decide how to allocate the responsibility of meeting this target between Capital (firms) and Labour (households).

You (representing either labour or capital), and each of your group members, will be given an initial endowment of 10 tokens. You must decide how much of this endowment to invest in the environment. When you invest in the environment, you are investing in the reduction of harmful greenhouse gas emissions to combat climate change.

Procedure of the Experiment

Each member of the group receives 10 tokens and has to decide how to invest these 10 tokens.

You can contribute to either a Private Account or a Public Account.

You can either:

- (i) put all these 10 tokens into your Private Account and nothing into the Public Account
- (ii) put nothing into the Private Account and all 10 tokens into the Public Account
- (iii) put some of the 10 tokens into the Public Account and the remainder in the Private Account.

Therefore, each group member has to decide for himself or herself how much of his or her 10 tokens to put into the Private Account and the Public Account.

By contributing to the Public Account you are choosing to invest in the environment and combat climate change through a reduction of harmful greenhouse gas emissions.

Income from the Private Account

Capital and Labour representatives earn income from investing in the Private Account.

The Private Account represents investment opportunities other than investing in the environment (i.e. in mitigation). Because Capital (Firms) can more easily invest in productive (income-generating) activities as compared to Labour (households), Capital earns a higher return from money invested in the Private Account relative to Labour.

Capital's income from the Private Account:

For each token that a Capital player chooses to invest in the Private Account, he/she will earn 12 tokens:

$$\text{Capital Player's private income} = (\text{tokens invested in the Private Account}) \times 12$$

Labour's income from the Private Account:

For each token that a Labour player chooses to invest in the Private Account, he/she will earn 6 tokens:

$$\text{Labour Player's private income} = (\text{tokens invested in the Private Account}) \times 6$$

Example 1:

How much PRIVATE income do Capital and Labour earn if both players invest **0** tokens in the **Public Account**?

Answer:

$$\text{Capital Player's private income} = (\text{tokens invested in the Private Account}) \times 12$$

$$\text{Capital Player's private income} = 10 \times 12$$

$$\text{Capital Player's private income} = 120$$

$$\text{Labour Player's private income} = (\text{tokens invested in the Private Account}) \times 6$$

$$\text{Labour Player's private income} = 10 \times 6$$

$$\text{Labour Player's private income} = 60$$

(If a player invests 0 tokens in the **public account**, then they keep all 10 tokens for their **private account**)

Example 2:

How much PRIVATE income do Capital and Labour earn if both players invest 4 tokens in the **Public Account**?

Answer:

Capital Player's private income = (tokens invested in the Private Account) × 12

Capital Player's private income = 6 × 12

Capital Player's private income = 72

Labour Player's private income = (tokens invested in the Private Account) × 6

Labour Player's private income = 6 × 6

Labour Player's private income = 36

(If a player invests 4 tokens in the **public account**, then they keep all 6 tokens for their **private account**)

Contributions to the Public Account (reducing emissions)

As previously mentioned, when you allocate tokens to the Public Account, you are investing in the environment and reducing greenhouse gas emissions. Therefore, the total sum of tokens in the Public Account represents the emissions reductions of your group.

Because firms emit more pollution than households, it is cheaper for them – relative to households - to reduce emissions. This means that Capital is able to reduce more emissions with 1 token than Labour is able to.

Therefore **Capital's contribution to the Public Account is multiplied by 20** while **Labour's contribution to the Public Account is multiplied by 10**.

The total amount of pollution reduced by your group is calculated as follows:

$$\text{Emissions reduced} = (K_1 \times 20) + (K_2 \times 20) + (L_1 \times 10) + (L_2 \times 10)$$

Where K_1 = Capital Player 1's contribution to the Public Account

K_2 = Capital Player 2's contribution to the Public Account

L_1 = Labour Player 1's contribution to the Public Account

L_2 = Labour Player 2's contribution to the Public Account

We can see from the formula that Capital is able to contribute more to emissions reductions. This is also clear from the table below which shows **emissions reductions per token**.

Emissions reduction per token contributed by Capital and Labour

Tokens	Capital	Labour
0	0 (0*20)	0 (0*10)
1	20 (1*20)	10 (1*10)
2	40 (2*20)	20 (2*10)
3	60 (3*20)	30 (3*10)
4	80 (4*20)	40 (4*10)
5	100 (5*20)	50 (5*10)
6	120 (6*20)	60 (6*10)
7	140 (7*20)	70 (7*10)
8	160 (8*20)	80 (8*10)
9	180 (9*20)	90 (9*10)
10	200 (10*20)	100 (10*10)

- When Capital allocates 5 tokens to the Public Account, there is a reduction of 100 units of emissions
- When Labour allocates 5 tokens to the Public Account, there is a reduction of 50 units of emissions

So if Capital contributes 1 token to the Public Account, the decrease in emissions is greater than if Labour contributes 1 token.

Example 1:

Calculate the reduction in emissions if both Capital players each contribute **10** tokens to the Public Account and both Labour players each contribute **0** tokens to the Public Account.

$$\begin{array}{cccc}
 K_1 & K_2 & L_1 & L_2 \\
 \hline
 K_1 \times 20 & K_2 \times 20 & L_1 \times 10 & L_2 \times 10 \\
 \mathbf{(10)} \times 20 & \mathbf{(10)} \times 20 & \mathbf{(0)} \times 10 & \mathbf{(0)} \times 10
 \end{array} = 400$$

400
0

In this case, pollution is reduced by **400** units.

Example 2:

Calculate the reduction in emissions if both Capital players each contribute **0** tokens to the Public Account and both Labour players each contribute **10** tokens to the Public Account

K_1	K_2	L_1	L_2	
$K_1 \times 20$	$K_2 \times 20$	$L_1 \times 10$	$L_2 \times 10$	= 200
(0) $\times 20$	(0) $\times 20$	(10) $\times 10$	(10) $\times 10$	
$\underbrace{\hspace{10em}}$ 0		$\underbrace{\hspace{10em}}$ 200		

In this case, pollution is reduced by **200** units.

Example 3:

Calculate the reduction in emissions if Capital₁ contributes **3** tokens, Capital₂ contributes **2** tokens, Labour₁ contributes **6** tokens and Labour₂ contributes **7** tokens to the Public Account, respectively.

K_1	K_2	L_1	L_2	
$K_1 \times 20$	$K_2 \times 20$	$L_1 \times 10$	$L_2 \times 10$	= 230
(3) $\times 20$	(2) $\times 20$	(6) $\times 10$	(7) $\times 10$	
$\underbrace{\hspace{10em}}$ 100		$\underbrace{\hspace{10em}}$ 130		

In this case, pollution is reduced by **230** units.

Income from the Public Account (reducing emissions)

Players earn a payoff/income from investing in the Public Account – there is a payoff from reducing emissions. You can think of this payoff as representing a package of benefits from emissions reductions: increased air quality, reduced probability of environmental disasters, greater rainfall in certain parts of the country (greater availability of water resources) and a reduced threat to public health from the increased incidence of malaria.

As previously mentioned, once every group member has decided how much to contribute to the Public Account, the experimenter will **multiply capital's total contribution by 20 and labour's total contribution by 10 (this determines the groups' contribution to emission reduction)**. The total amount in the Public Account will then be divided equally between the **four** group members.

So the income each group member receives from the Public Account is calculated as follows:

$$\frac{(K_1 \times 20) + (K_2 \times 20) + (L_1 \times 10) + (L_2 \times 10)}{4}$$

Where K_1 contribution = Capital Player 1's contribution to the Public Account

K_2 contribution = Capital Player 2's contribution to the Public Account

L_1 contribution = Labour Player 1's contribution to the Public Account

L_2 contribution = Labour Player 2's contribution to the Public Account

Note that because the environment is a public good no one can be excluded from reaping the benefits of emissions reductions so every group member receives the same amount of money out of the Public Account, **no matter what his or her contribution was.**

Example 1:

Calculate your income from the Public Account if both Capital players each contribute **3** tokens to the Public Account and both Labour players each contribute **6** tokens to the Public Account.

Your income from the Public Account: (this income is the same for all group members)

K_1	K_2	L_1	L_2
$K_1 \times 20$	$K_2 \times 20$	$L_1 \times 10$	$L_2 \times 10$
(3) × 20	(3) × 20	(6) × 10	(6) × 10
120		120	
4			

= 60 tokens

Example 2:

Calculate your income from the Public Account if both Capital players each contribute **6** tokens to the Public Account and both Labour players each contribute **3** tokens to the Public Account.

Your income from the Public Account:

K_1	K_2	L_1	L_2
$K_1 \times 20$	$K_2 \times 20$	$L_1 \times 10$	$L_2 \times 10$
(6) × 20	(6) × 20	(3) × 10	(3) × 10
240		60	
4			

= 75 tokens

TOTAL Income

Follow **3 steps** to calculate your **total income**:

Step 1: Calculate your income from the Private Account:

$$\text{Capital Player's private income} = (\text{tokens invested in the Private Account}) \times 12$$

$$\text{Labour Player's private income} = (\text{tokens invested in the Private Account}) \times 6$$

Step 2: Calculate your income from the Public Account:

$$\frac{(K_1 \times 20) + (K_2 \times 20) + (L_1 \times 10) + (L_2 \times 10)}{4}$$

Step 3: Add your PRIVATE income and your PUBLIC income together

$$\text{Total income} = \text{Private Income} + \text{Public Income}$$

Now let's use the payoff tables that have been handed out to you (orange sheet) to look at the following symmetric examples:

Example 1:

Calculate your TOTAL income if all players contribute **0** tokens to the Public Account.

Example 2:

Calculate your TOTAL income if both Capital players each contribute **10** tokens to the Public Account and both Labour players each contribute **10** tokens to the Public Account.

Example 3:

Calculate your TOTAL income if both Capital players each contribute **10** tokens to the Public Account and both Labour players each contribute **0** tokens to the Public Account.

Example 4:

Calculate your TOTAL income if both Capital players each contribute **0** tokens to the Public Account and both Labour players each contribute **10** tokens to the Public Account.

Emissions reduction target

The South African government has set a ***national emission reduction target of 240***. This target is in line with government's multilateral climate change obligations.

The Government is committed to meeting this target and asks Capital and Labour players to ensure that this target is met.

However, at this stage, players won't be penalised for failing to meet the target.

Government envisions that this target will be split between Capital and Labour.

As evident from the table below, the emissions reduction target of 240 can be met through Capital and Labour investing different combinations of tokens in the Public Account.

You can look on your calculator to see some of the many combinations of Capital and Labour contributions that amount to an emissions reduction of 240. We will go through two examples in a moment.

Emissions reduction per token contributed by Capital and Labour

Tokens	Capital	Labour
0	0 ($0*20$)	0 ($0*10$)
1	20 ($1*20$)	10 ($1*10$)
2	40 ($2*20$)	20 ($2*10$)
3	60 ($3*20$)	30 ($3*10$)
4	80 ($4*20$)	40 ($4*10$)
5	100 ($5*20$)	50 ($5*10$)
6	120 ($6*20$)	60 ($6*10$)
7	140 ($7*20$)	70 ($7*10$)
8	160 ($8*20$)	80 ($8*10$)
9	180 ($9*20$)	90 ($9*10$)
10	200 ($10*20$)	100 ($10*10$)

Remember that Capital is able to reduce more emissions with 1 token than Labour is able to!

The following examples indicate the reduction in emissions through Capital and Labour investing different combinations of tokens in the Public Account.

Example 1:

$$\begin{array}{cccc}
 K_1 & & K_2 & & L_1 & & L_2 \\
 K_1 \times 20 & + & K_2 \times 20 & + & L_1 \times 10 & + & L_2 \times 10 \\
 \textcircled{0} \times 20 & & \textcircled{0} \times 20 & & \textcircled{0} \times 10 & & \textcircled{0} \times 10 \\
 \hline
 \underbrace{\hspace{10em}}_{0} & & \underbrace{\hspace{10em}}_{0} & & & & = 0
 \end{array}$$

Government's pollution reduction target is not met.

Example 2:

$$\begin{array}{cccc}
 K_1 & & K_2 & & L_1 & & L_2 \\
 K_1 \times 20 & + & K_2 \times 20 & + & L_1 \times 10 & + & L_2 \times 10 \\
 \textcircled{4} \times 20 & & \textcircled{4} \times 20 & & \textcircled{4} \times 10 & & \textcircled{4} \times 10 \\
 \hline
 \underbrace{\hspace{10em}}_{160} & & \underbrace{\hspace{10em}}_{80} & & & & = 240
 \end{array}$$

Government's pollution reduction target is met.

Note: the emission reduction target has been met with all players contributing 4 tokens. This means that each Capital player reduced emissions by 80 while each Labour player reduced emissions by 40.

Example 3:

$$\begin{array}{cccc}
 K_1 & & K_2 & & L_1 & & L_2 \\
 K_1 \times 20 & + & K_2 \times 20 & + & L_1 \times 10 & + & L_2 \times 10 \\
 \textcircled{3} \times 20 & & \textcircled{3} \times 20 & & \textcircled{6} \times 10 & & \textcircled{6} \times 10 \\
 \hline
 \underbrace{\hspace{10em}}_{120} & & \underbrace{\hspace{10em}}_{120} & & & & = 240
 \end{array}$$

Government's pollution reduction target is met.

Note: the emission reduction target has been met with Capital players contributing 3 tokens and Labour players contributing 6 tokens. This means that all players have reduced emissions by 60.

Example 4:

$$\begin{array}{ccccccc} & K_1 & & K_2 & & L_1 & & L_2 \\ \hline & K_1 \times 20 & + & K_2 \times 20 & + & L_1 \times 10 & + & L_2 \times 10 \\ & \mathbf{(10)} \times 20 & & \mathbf{(10)} \times 20 & & \mathbf{(10)} \times & & \mathbf{(10)} \times 10 \\ & & & & & 10 & & \\ \hline & \underbrace{\hspace{10em}} & & \underbrace{\hspace{10em}} & & & & \\ & 400 & & 200 & & & & \\ & & & & & & & = 600 \end{array}$$

Government's pollution reduction target is exceeded.

Please consider your summary table once again (your pink form).

Univeristy of Cape Town

Your experiment number: _____

Decision Sheet

Experiment 1

You have been allocated 10 tokens. You must decide how to allocate these tokens between the Public and Private Accounts.

Government has publicly announced a national Emission Reduction Target of 240 in line with its multilateral obligations. **The government is committed to meeting this target and asks Capital and Labour to ensure that the target is met.** However, at this stage, players won't be penalised for failing to meet the target.

Please write down how many tokens you want to contribute to **the Public Account (invest in the environment)**:

tokens

(You can only invest a maximum of 10 tokens; use only whole numbers; the rest is automatically put into the Private Account)

Communication Game

Once again, you have been allocated ten tokens which you must allocate between the Private Account and the Public Account.

You have now been assigned to a new group; your factor of production allocation **has not changed**.

The South African government has set a ***national emission reduction target of 240***. This target is in line with government's multilateral climate change obligations.

The Government is committed to meeting this target and asks Capital and Labour players to ensure that this target is met.

However, at this stage, players won't be penalised for failing to meet the target.

The target of 240 can be reached through Capital and Labour investing different combinations of tokens in the Public Account.

During this experiment, **you may communicate online with the players in your group** in order to discuss how much you each think each player should each contribute to the Public Account.

You now have an opportunity to discuss what would be best for the group and decide how to meet the target.

Towards the end of the online discussion session, once you have discussed what you each feel is an appropriate contribution from each player, each group must vote on the amount of tokens that Capital and Labour should contribute to the Public Account. You will be prompted when it is time to vote.

Note that whatever group consensus is reached, the final decision you make is still your own and your decision will not be made public.

If you have any questions or are unsure about anything please raise your hand. Once everyone is ready you may begin communicating online with the members of your group.

Please consider your summary table once again (your yellow form).

Your experiment number: _____

Decision Sheet

Experiment 2

Once again, you have been allocated 10 tokens. You must decide how to allocate these tokens between the Public and Private Accounts.

Government has publicly announced a national Emission Reduction Target of 240 in line with its multilateral obligations. **The government is committed to meeting this target and asks Capital and Labour to ensure that the target is met.** However, at this stage, players won't be penalised for failing to meet the target.

Please write down how many tokens you want to contribute to **the Public Account (invest in the environment)**:

tokens

(You can only invest a maximum of 10 tokens; use only whole numbers; the rest is automatically put into the Private Account)

Appendix D. Emission reduction

Table D1. Emission reduction, by player type (per ECU invested in mitigation)

ECUs	Player-type	
	Low-MCA	High-MCA
0	0	0
1	20	10
2	40	20
3	60	30
4	80	40
5	100	50
6	120	60
7	140	70
8	160	80
9	180	90
10	200	100

Appendix E. Average contributions

Table E1. Average contributions

	Sequence 2			Sequence 3		
	Avg. <i>n</i> =68	Low- MCA <i>n</i> =34	High- MCA <i>n</i> =34	Avg. <i>n</i> =68	Low- MCA <i>n</i> =34	High- MCA <i>n</i> =34
Baseline	2.78 (2.56)	2.85 (2.36)	2.71 (2.78)	3.63 (3.16)	4 (3.18)	3.26 (3.14)
Comm.	3.82 (3.94)	3.56 (3.59)	4.09 (4.31)	5.06 (4.44)	5.94 (4.24)	4.18 (4.52)

Note: Standard deviations are presented in parenthesis

Appendix F. Auxiliary regressions

Table F1. Auxiliary regressions for low-MCA players

Variables	<i>Dep. variable: Contribution level</i>	
	(1) <i>(Baseline & Comm.)</i>	(2) <i>(Baseline & Comm.)</i>
	T2	T3
Session	-0.847 (0.725)	-1.724 (1.094)
Communication	0.727 (0.558)	1.969** (0.737)
Female	0.998 (0.748)	-0.125 (1.154)
Age < 20	1.026 (0.650)	-1.627 (1.200)
GHGs	2.217** (0.846)	-3.123** (1.167)
Human	-0.261 (0.790)	1.137 (1.414)
Climate policy ¹	-	4.669** (1.505)
Constant	1.651 (1.541)	3.866** (1.487)
p	0.000	0.000

Note:

- Standard errors are adjusted for clustering; * and ** indicate significance at the 5% and 1% level, respectively
- ¹ Variable excluded from regression because all participants indicate South Africa should adopt emission reduction targets

Risk Attitudes and Adaptation: Experimental Evidence from a Flood-Prone Urban Informal Settlement in South Africa

Kerri Brick^φ

Abstract

This study characterises the risk attitudes of a sample of individuals living in a flood-prone, urban informal settlement, assuming Prospect Theory as the primary model for decision-making under uncertainty. A number of Cape Town's informal settlements are situated on the low-lying, flood-prone Cape Flats, where inadequate infrastructure combined with a high water table leave residents extremely vulnerable to flooding. Vulnerability to flood risk (and the associated diminished wellbeing and damage to property and possessions that are experienced in the aftermath) are determined, in part, by participants' adaptation strategies. In this context, the objective of this paper is to determine the extent to which risk attitudes are correlated with choice of adaptation strategy. Risk attitudes are elicited from participants' choices over a series of lottery tasks for real monetary prizes. Lottery tasks are provided in either a gain, mixed or loss framing. The results indicate that individuals adopting more effective (and costly) adaptation strategies are more risk averse.

Keywords: risk aversion; Prospect Theory; uncertainty; flooding; adaptation

^φ Many thanks to Glenn Harrison, Elisabet Rutström and Morten Lau for providing the Stata codes, and to Morten Lau and CEEPA affiliates for commenting on earlier drafts.

1 Introduction

This study characterises the risk attitudes of a sample of individuals living in a flood-prone urban informal settlement in Cape Town, South Africa. The risk attitudes of this unique sample and, more specifically, the relationship between risk attitudes and flood adaptation, are particularly interesting given that decisions related to flood adaptation involve significant stakes. In particular, vulnerability to flood risk (and associated loss of property, possessions and diminished wellbeing) are determined, in part, by decisions over how to mitigate the risk of damage from flooding (in other words, choice of adaptation strategy). In this context, assuming Prospect Theory (PT) as the primary model for decision-making under uncertainty,¹ the objective of this paper is to determine the extent to which risk attitudes are correlated with choice of adaptation strategy.

By way of background, a number of Cape Town's informal settlements are situated on the low-lying, flood prone Cape Flats, where inadequate infrastructure combined with a high water table leave residents extremely vulnerable to flooding. These informal settlements are flooded annually during the wet, rainy season, resulting in damage to dwellings and property and, in some cases, negatively affecting health as residents are left living in damp conditions. With the frequency of extreme weather events (such as storms and floods) projected to increase with climate change (Mukheibir and Ziervogel 2006), coupled with few prospects for short-term relocation, this situation is likely to worsen.²

As will be discussed in the proceeding section, while there are a number of adaptation strategies that individuals can adopt to reduce their vulnerability to the negative impacts of a flood (for

¹ As will be discussed later in the paper, the PT results are compared to an Expected Utility Theory model – the results of which are included in an appendix.

² The City of Cape Town (2009) defines flooding as a “temporary rise in water level or the overflow of water onto land not normally covered by water that results in socio-economic disruption, property damage or threatens the health and safety of the public” (City of Cape Town 2009: 5). Informal settlements are considered as being flooded when water is covering floors and areas around dwellings for more than 48 hours (City of Cape Town 2009). Note that the severity of flooding (measured in terms of displaced households) does vary across years. Major flood events were experienced in July 2001, August 2004, July 2007, July 2008 and July 2009, with the number of households displaced by flooding estimated to be 11 000, 4 500, 8 000, 8 600 and 8 050, respectively (Ziervogel and Smit 2009, City of Cape Town 2009). Flood risk within this urban-settlement context differs from more commonly understood flood risk emanating from coastal, riverine or estuarine flooding (Holloway *et al.* 2008). Types of flooding within this context include ponding: where rain pools on the surface of the ground in poorly drained, low-lying areas; seepage: water rises up to the ground surface (usually in areas where there is a high water table); surface run-off: water drains off hardened surfaces (such as roads) in the absence of adequate stormwater drainage; leaking: indoor flooding occurs as rainwater leaks through inadequately water-proofed and poorly constructed structures (for example through the roof) (Holloway *et al.* 2008).

example raising one's home above ground level and/or slanting the roof), there is substantial variation in the degree to which these strategies are implemented. In this context, Olorunfemi (2010) highlights two major factors aggravating flood disasters: (i) building too low to the ground; and (ii) leaking roofs. In particular, improvement of building structures is considered to be an important component of community-led measures to reduce risk of flooding (Olorunfemi 2010). In line with this, in its Winter Preparedness Strategy, the City of Cape Town notes that even when informal settlements are situated on relatively well sloped land, flooding of dwellings is inevitable given both construction techniques and standards, including, in particular, floors at ground level and leaking roofs (City of Cape Town 2009).

The risk of a household being impacted by flooding is therefore strongly influenced by the level of active engagement in adaptive strategies by the household occupants. Since experiment participants live in the same geographical area and are exposed to largely the same risk of flooding, the experiment reported here examines whether choice of adaptation strategy is correlated with risk attitudes.³

Much of the literature around adaptation focuses on the technology-adoption decisions of small-scale farmers. In this context, studies indicate that risk preferences impact on farmers' adaptation choices. Specifically, Liu (2008), who relates Chinese farmers' risk attitudes to the adoption of a new production technology, finds that farmers who are more risk and loss averse adopt new technologies later. Similarly, Simtowe (2006) finds that the adoption of hybrid maize is lower for Malawian farmers who exhibit risk aversion around the use of fertiliser (a complementary input for maize).⁴

There is a large experimental literature covering the elicitation of risk preferences in both developed and developing countries: Binswanger (1980) in India, Holt and Laury (2002) in the United States (US), Barr (2003) in Zimbabwe, Wik *et al.* (2004) in Zambia, Engle-Warnick *et al.* (2007) in Peru, Yesuf and Bluffstone (2009) in Ethiopia, Harrison *et al.* (2010) in Ethiopia,

³ Given that the decision to invest in adaptation entails a trade-off between short-term costs and longer-term benefits (this is probably most applicable to the strategy of slanting the roof relative to using plastic sheeting), future work in the area of adaptation should additionally include elicitation of discount rates. Furthermore, studies relating risk preferences to adaptation assume that subjects have beliefs around the probabilities of a particular outcome. However, in the context of climate change and adaptation, as the likelihood of an extreme future event (such as drought or flood) is unknown, the decision to adapt is likely characterized by both risk and ambiguity (Alpizar *et al.* 2011).

⁴ More broadly, a number of studies find adoption of new farming technologies to be correlated with wealth (Croppenstedt *et al.* 2003, Chirwa 2005, Dercon and Christiaensen 2011).

India and Uganda, Humphrey and Verschoor (2004a, 2004b) in Uganda, Harrison *et al.* (2007) in Denmark, Harrison and Rutström (2009) in the US, Eckel and Grossman (2002, 2008) in the US, Galarza (2009) in rural Peru, Liu (2008) in China, and Tanaka, Camerer and Nguyen (2010) in Vietnam.

Many of the risk experiments conducted in developing countries assume that decisions under uncertainty are characterised by Expected Utility Theory (EUT) solely as the curvature of the utility function (Binswanger 1980, Bar 2003, Wik *et al.* 2004, Yesuf and Bluffstone 2009). However, several studies have found observed behaviour to be inconsistent with EUT (Tversky and Kahneman 1992, Humphrey and Verschoor 2004a and 2004b, Mosley and Verschoor 2005), while others have found evidence of heterogeneity in decision making, such that subjects' choices are not best represented by one single theory (Harrison and Rutström 2009; Harrison *et al.* 2010).

In Original Prospect Theory (OPT), developed by Kahneman and Tversky (1979), risk preferences are also influenced by loss aversion (the value function is steeper for losses than for gains) and probability weighting (Andersen *et al.* 2010). With the evolution towards Cumulative Prospect Theory (CPT), Tversky and Kahneman (1992) apply the rank-dependent method introduced by Quiggin (1982) separately over gains and losses to transform cumulative probabilities into subjective ones (Fennema and Wakker 1997). If a participant subjectively underweights probabilities, s/he behaves as if the probability of a particular outcome occurring is less than that of the lottery probability associated with that outcome (Harrison *et al.* 2010). In the gain frame, this manifests as risk aversion, while in the loss frame, it is synonymous with risk seeking behaviour (Harrison and Swarthout 2012). Furthermore, while EUT implies local asset integration in terms of which individuals evaluate net gains and losses, CPT assumes that individuals do not locally asset-integrate, and rather evaluate gross gains and losses (Harrison and Swarthout 2012).

Laboratory and field experiments focusing on lottery-choice tasks for real monetary stakes provide some evidence of loss aversion and/or probability weighting (Wik *et al.* 2009, Yesuf and Bluffstone 2009, Harrison and Rutström 2009, Harrison *et al.* 2010, Tanaka *et al.* 2010, Liu 2008, Humphrey and Verschoor 2004a and 2004b). More specifically, Tanaka, Camerer and Nguyen (2010) measure risk attitudes in Vietnam using a mix of gain-only and gain-and-loss lotteries. The authors report evidence of risk aversion, loss aversion, and the overweighting of

low probabilities. Liu (2008) replicates the design of Tanaka *et al.* (2010) with Chinese cotton farmers, finding that the farmers who are more loss averse adopt a particular technology later while farmers who overweight small probabilities adopt earlier. These findings signal the impact of loss aversion on individuals' decision-making. Harrison *et al.* 2010, conducting risk experiments in India, Ethiopia and Uganda, find that subjects behaving in accordance with OPT have a tendency to underweight probabilities. The authors, noting that the OPT specification captured general pessimism among the participants, account for this trend by noting that the visited regions were experiencing drought at the time of the field experiments. Humphrey and Verschoor (2004a, 2004b) find observed behaviour to be consistent with probability weighting.

With respect to the specification of the CPT model reported here, a Constant Relative Risk Averse (CRRA) utility function is defined separately over gains and losses relative to a reference point, which is assumed to be zero. In addition, the experiment adopts the probability weighting function suggested by Tversky and Kahneman (TK) (1992) (Tversky and Kahneman 1992, Andersen *et al.* 2010).⁵

The experiment reported here replicates the design of Harrison and Rutström (2009), whereby subjects are provided with 60 lottery tasks and, for *each* lottery task, choose between two lottery pairs. While the participants partake in either a gain, mixed or loss frame, endowments are used to equalise the payoffs across the frames. Participants also complete a survey capturing information on their demographic characteristics as well as their attitudes to flood adaptation.

The results of the CPT model suggest the fourfold pattern of risk aversion typically assumed under PT, namely: (i) risk seeking over low probability gains; (ii) risk aversion over high-probability gains; (iii) risk aversion over low probability losses; and (iv), risk seeking over high probability losses (Harbaugh *et al.* 2009, Tversky and Kahneman 1992). Specifically, the utility function is found to be concave (reflecting risk aversion) over gains and convex (reflecting risk seeking) over losses. In addition, in both the gain and loss frames, the TK inverse-S probability weighting function reflects overweighting of low probabilities and underweighting of high probabilities (although this result is quantitatively small).

⁵ As will be discussed, the TK probability weighting function is compared to other popular weighting functions and is found to be broadly consistent.

With regard to flood adaptation, the results suggest that flood adaptation is correlated with risk preferences. Specifically, the results indicate that individuals that (i) elect to do nothing (in terms of adaptation); (ii) rely solely on plastic sheeting for their roof or floor; and (iii), raise their home above ground, are less risk averse relative to individuals who (iv) slant their roofs to facilitate rainwater runoff. More detailed information about these adaptation strategies is provided in a subsequent section.

The paper proceeds as follows: Section 2 provides general background and sample specifics, while Section 3 describes the experiment design, procedures and recruitment. In Section 4, the estimation method is discussed, Section 5 provides the results of the CPT model, and Section 6 concludes.

2 General background and sample specifics

As alluded to above, many of Cape Town's informal settlements are situated on the flood prone Cape Flats, a low lying area with a high water table. The informal settlements themselves are often situated in low lying areas, in flood plains, adjacent to rivers and canals or in retention ponds (City of Cape Town 2009). Amid inadequate stormwater infrastructure and refuse blockages in drainage pipes, the residents of these marginalised communities are extremely vulnerable to the risk of flooding (Bouchard et al. 2007). As such, bouts of heavy rainfall during the wet winter months give rise to pools of stagnant water in and around informal dwellings as the ground becomes saturated (Ziervogel and Smit 2009).

Flooding does not affect one or two people, but rather, entire communities. A 2005 survey of three informal settlements in the Cape Flats revealed that 83% of residents had been affected by flooding (City of Cape Town 2005). As part of an inter-departmental Winter Preparedness Strategy, the Flooding and Storm Planning Task Team of the City of Cape Town has identified 20 informal settlements that are at high risk of winter flooding, and an additional 14 at such high risk that they need to be relocated (*personal communication with City officials*). The reality, however, is that relocation is a very long, protracted and difficult process, characterised by land shortages and objections from people living in surrounding areas when empty land is identified (*personal communication*). In addition, the significant housing backlog means that

the allocation of formal housing to informal sector residents is not likely to be a short-term solution (*personal communication*).

In the experiment reported here, 174 individuals were recruited from BM section in Khayelitsha, a particularly flood-prone urban informal settlement situated on the Cape Flats. Table 1 reflects some general sample statistics, both for the sample as a whole and for each experiment treatment (gain, mixed and loss). Note that these treatments were conducted on separate days. On average, participants are 32 years old and around 60% are female (although there is considerable variation across the three treatments).

In terms of highest level of education completed, the majority of the sample (across all treatment frames) has either obtained some high school (secondary) education or matriculated with their school-leaving (Grade 12) certificate; however, the proportion of participants that has completed Grade 12 is substantially higher in treatment 3 (loss frame). Participants in this treatment are also younger, on average, and have almost certainly benefitted from more universal school attendance. As such, it is important to control for age and education effects in the subsequent analysis.

For around 78% of the sample, *household* income is less than \$290 (R3 000) per month.⁶ Around 71% of households receive at least one government grant. Specifically, nearly 16% of households receive a pension, over 61% receive a child care grant, and around 6% receive a disability grant. Unemployment is high, at around 39% of the sample.

Responses to the survey indicate that approximately 80% of the sample experience flooding on an annual basis (table 2).⁷ Around 36% of subjects describe their experience of flooding as water coming up through the ground, just over 49% describe it as water coming in through the roof, and almost 15% describe it as both. Just under 10% of the sample report never having experienced flooding.

⁶ R/\$ = R10.36 on 18 May 2014

⁷ Note that the survey merely asked respondents questions around their experiences of the frequency of flooding. The questions did not define flooding – for example that the floor of the dwelling and surrounding areas are covered with water for a minimum of 48 hours. Responses are thus to some extent subjective.

There are a number of individual adaptation strategies that residents and communities can adopt in a bid to reduce the risk of flooding. Such strategies include: ensuring that one's floor is elevated above ground level on pallets, stilts or sandbags; performing general maintenance on one's roof before the start of the rainy season; ensuring one's roof is slanted to assist with rainwater runoff; securing plastic sheeting to one's roof prior to the advent of the rainy season; making sure that the trenches/channels around one's home are not blocked with refuse (Bouchard et al. 2007, *personal communication*).

Table 1. Sample statistics (participants from BM Section, Khayelitsha)

	All <i>n</i> = 174	Treatment 1 (Gains) <i>n</i> = 60	Treatment 2 (Mixed) <i>n</i> = 60	Treatment 3 (Loss) <i>n</i> = 54
Age				
Mean	32.42	35.42	31.87	29.65
Std. dev.	9.88	9.74	10.87	7.95
Median	30.00	34.50	30.00	28.00
Female (%)	0.60	0.67	0.65	0.48
Education (%)				
No schooling	0.01	0.02	0.00	0.00
Incomplete primary school	0.01	0.00	0.02	0.00
Complete primary school	0.03	0.03	0.07	0.00
Incomplete secondary school	0.48	0.73	0.42	0.26
Grade 12 (matric)	0.47	0.22	0.49	0.74
HH size				
Mean	5.21	5.30	5.49	4.79
Std. dev.	2.32	2.11	2.27	2.57
Median	5.00	5.00	5.00	4.00
HH income bracket (%)				
R0 – R2000	0.54	0.62	0.45	0.56
R0 – R3000	0.78	0.82	0.68	0.83
Unemployed (%)	39.08	46.67	36.67	33.33

These strategies would go some way to reducing the risk of flooding. However, notwithstanding education initiatives by local government, the levels of implementation across households are highly varied (*personal communication*). More specifically, table 2 illustrates the uptake of various flood adaptation strategies amongst the sample in this experiment. Approximately 10% of the sample has done nothing to mitigate the risk of flooding (around half of these individuals have never experienced flooding). Around 37% of participants have raised their home above ground level with the use of pallets (16%), stilts (7%) and sandbags

(18%).⁸ Around 45% of subjects have put plastic sheeting on their roofs, and 14% on their floors. Less than 9% of the sample has raised one side of their roof to aid in rainwater runoff.

Table 2. Sample statistics: experience of flooding and flood mitigation strategies

	All <i>n</i> = 174	Treatment 1 (Gains) <i>n</i> = 60	Treatment 2 (Mixed) <i>n</i> = 60	Treatment 3 (Loss) <i>n</i> = 54
Annual flooding (%)	0.80	0.75	0.85	0.80
<i>Flood risk mitigation strategies (%)</i>				
Do nothing	0.10	0.15	0.08	0.06
Use pallets to raise home above ground	0.16	0.15	0.15	0.19
Use stilts to raise home above ground	0.07	0.05	0.13	0.03
Use bags of sand to raise home above ground	0.18	0.15	0.15	0.24
Put plastic sheeting on the roof	0.45	0.43	0.48	0.43
Put plastic sheeting on the floor	0.14	0.13	0.10	0.20
Raise one side of the roof	0.09	0.07	0.03	0.17
Perform general maintenance on the roof	0.22	0.25	0.22	0.18
Move to another area	0.01	0.00	0.02	0.00
Waiting to be moved to another area	0.14	0.17	0.15	0.09
Waiting to be given formal housing	0.22	0.27	0.23	0.17

The consequences of flooding are far reaching and include damage to the informal dwelling as well as the contents therein; after a flood, unpaved roads in and around the flooded area often become inaccessible, hindering the efforts of relief teams and making it difficult for residents to leave the area; stagnant pools of flood water can become polluted and a hazard to health (Ziervogel and Smit 2009); communal toilets, taps and rubbish skips in the flooded area can become inaccessible.

The survey also captures information on the aftermath of a flood. Here again, the feedback obtained indicates that the level of damage or discomfort experienced by households varies significantly. Around 33% of the sample report damage to the structures of their homes, with 48% reporting damage to their possessions. Approximately 24% of those sampled indicate that their floor is either wet or underwater following flooding. Over 30% indicate that the roads around their home become wet and muddy, making it difficult for people to access the area. Almost 30% report difficulties in reaching communal toilets. Just over 43% report that people (especially children) become sick from the pools of stagnant flood water. Finally, nearly 26% report electricity outages. When asked if they elected to stay in an emergency shelter (for example, a community hall) after a flood event, around 35% indicate that they have moved to

⁸ Note that some individuals have used more than one method to raise their home (for example pallets and sandbags)

an emergency shelter in the wake of a flood, while just over 52% report a preference for remaining in their dwelling for fear that their belongings will be stolen once the dwelling is vacated.

3 Experiment

The experiment replicates the design of Harrison and Rutström (2009), which is itself an extension of the design of Hey and Orme (1994). Subjects are presented with 60 lottery tasks. In each lottery task, subjects choose between two lottery pairs (Lottery 1 or Lottery 2).

There are three treatments: a gains-only treatment, a mixed (gains and losses) treatment, and a loss treatment. In the gain frame, there is no endowment, and the lottery prizes are R0, R50, R100 and R150. In the loss frame, the lottery prizes are -R150, -R100, -R50 and R0. In addition, participants in the loss frame are provided with an initial per game endowment of R150 so that total payoffs are equalised across the treatments. In the mixed frame, participants are provided with a R75 per game endowment, and the payoffs are R75, -R25, R25 and R75.

The probabilities of each prize vary with each lottery task (Appendix A reflects the probabilities used in the first 10 lottery tasks). In the first lottery task of the gain frame, if a participant chooses Lottery 1, s/he has a 13% chance of earning nothing, a 25% chance of earning R100 and a 62% chance of earning R150. Conversely, if s/he chooses Lottery 2, s/he is guaranteed R100. Appendix B displays the decision sheet for the first lottery task in the gains treatment. Subjects choose either Lottery 1 or Lottery 2 (no explicit indifference option was provided).

Average earnings (including the participation fee) in the gain, mixed and loss frames were \$22 (R228), \$25 (R261) and \$20 (210), respectively.

3.1 Procedures

The lottery probabilities are depicted as pie charts in Appendix B. In the experimental design, the probabilities are operationalised through the use of a spinning wheel. In as much as the experiment sample consists of participants with low levels of numeracy and education, great

care must be (and was) taken to make the lottery task as cognitively accessible as possible. While the actual probabilities associated with each lottery outcome are provided in the decision sheets, participants are able to supplement this metric by also looking at the graphics provided. By way of illustration, by looking at the pie charts in Appendix B (of the first lottery task), it is immediately apparent that, with Lottery 1, the participant has a significant chance of earning R150 and a small (but existent) chance of winning nothing. This is contrasted with Lottery 2, where it is clear that the participant is guaranteed to earn R100.

Using the random lottery incentive mechanism, two out of the 60 lottery tasks are randomly selected for playing and payment.⁹ In terms of the mechanics of the random selection: 60 pieces of paper, numbered 1 to 60 for the 60 lottery tasks, were placed in a bag; the two numbers drawn from the bag determined which lottery tasks were to be played for real money. The respective pie charts for both Lottery 1 and Lottery 2 of the selected lottery tasks were in turn placed on a spinning wheel. The combination of participants' preferences (i.e. whether Lottery 1 or Lottery 2 was chosen by a participant), as well as the outcome of the spinning wheel, determined the participants' payoff in the selected lottery task.

The three treatments were conducted on separate days. At each treatment, the same enumerator explained the instructions in detail. A projector was used to display the lottery tasks while the enumerator went through the instructions. The participants provided answers in printed booklets.

As mentioned above, at the start of each treatment, participants completed a survey which, in addition to capturing information on demographic characteristics, included a number of questions around participants' experience of flooding and their associated flood-mitigation strategies. In order to eliminate house money effects (as far as possible), in both the mixed and loss treatments, the endowment was framed as payment for filling out this survey. However, it was emphasised that any money earned throughout the course of the day would be added to

⁹ As discussed by Cox et al. (2014, 2014a) and Harrison and Swarthout.(2012a), assuming the axiom of reduction of compound lotteries, the random lottery incentive mechanism will only provide incentives for truthful reporting if subjects' preferences satisfy the independence axiom. As the independence axiom is rejected by CPT (for example the independence axiom implies linearity-in-probabilities while PT allows for non-linear probability weighting) (Andreoni et al. 2011) there is an implied inconsistency in using the random lottery incentive mechanism when estimating PT. Notwithstanding this discussion, the random lottery incentive mechanism is almost exclusively used as the incentive system in the risk-elicitation literature (for example, Holt and Laury 2002, Harrison and Swarthout 2012 who estimate CPT), notably because it avoids income effects.

this amount and any money lost while playing the lottery tasks would be deducted from this amount.

In addition to the endowment, participants in all treatments receive a participation fee of R50. Subjects were paid their total earnings at the end of the day by cash cheque.

An excerpt of the instructions is provided in Appendix C.

3.2 Recruitment

A list of those informal settlements flagged as being at high risk of flooding was obtained from local government. A number of these informal settlements are located within Khayelitsha, a large informal settlement situated on the Cape Flats. *BM section* in Khayelitsha was selected as the study site. The decision to use BM section was partly determined by accessibility, as strikes and protests in other sections of the informal settlement rendered inclusion of these areas at the time of the experiment impractical.

Using December 2011 aerial photography obtained from local government, 283 informal dwellings situated in the study site were randomly selected, and the GPS coordinates affiliated with each dwelling recorded. These GPS coordinates were used in the recruitment of individuals for participation in the experiment.

In total, 174 individuals were recruited (1 person per household); 60 individuals participated in the gains-only treatment, 60 individuals participated in the gains-and-losses treatment and 54 participated in the loss treatment.

4 Estimating risk preferences

The discussion that follows briefly outlines the elicitation procedure, and is derived from the following articles: Tversky and Kahneman (1992), Andersen *et al.* (2008, 2010 and 2012), Harrison and Rutström (2008 and 2009), Harrison *et al.* (2010) and Harrison and Swarthout (2012). Additional references are cited in the text.

Expected Utility Theory

While the results of the EUT model are provided in an appendix, a brief explanation of the EUT specification follows.

Under the EUT specification, expected utility for each lottery pair is the probability-weighted utility of the four lottery prizes, namely:

$$EU_i = \sum_{k=1,4} [p_k \times u_k]$$

where p_k is the objective probability associated with each lottery outcome k .

We assume a CRRA utility function whereby:

$$U(x) = \frac{(e + x)^{1-r}}{1-r}$$

where e reflects the endowment, x signifies the lottery prize, and r is the CRRA coefficient to be estimated, where $r = 0$ denotes risk neutrality, $r > 0$ denotes risk aversion, and $r < 0$ denotes risk seeking.

The expected utility (EU) of each lottery pair is “calculated for a candidate estimate of r ” (Harrison and Rutström 2009: 140) and the following index is calculated: $\nabla EU = EU_2 - EU_1$, where EU_2 is the expected utility associated with *Lottery 2* and EU_1 is the expected utility associated with *Lottery 1*.

A cumulative logistic distribution function, $\Phi(\nabla EU)$, is used to link the latent index, ∇EU_i , to subjects’ observed lottery choices. As this function transforms any value between $\pm\infty$ into a value between 0 and 1, the probability that *Lottery 2* is chosen over *Lottery 1* is $\Pr(EU_2 - EU_1) > 0 = \Phi(\nabla EU)$. As $\Phi(\nabla EU)$ reflects the probability of choosing *Lottery 2*, $[1 - \Phi(\nabla EU)]$ signifies the probability of choosing *Lottery 1*. *Lottery 2* is selected when $\nabla EU > 0$ or $\Phi(\nabla EU) > 0.5$.

The conditional log-likelihood is reflected as:

$$\ln L^{EUT}(r; y, X) = \sum [(\ln \Phi(\nabla EU_i) \times I(y_i = 1) + (\ln(1 - \Phi(\nabla EU_i)) \times I(y_i = 0))]$$

where $I(\cdot)$ is a function indicating the subject's choice: $y_i = 1(0)$ denotes the choice of Lottery 2 (Lottery 1), and X is a vector of individual characteristics (to be discussed in the following section).

The Fechner error specification is incorporated into the model to account for any behavioural errors made by the subjects (Hey and Orme 1994). In the case of a binary lottery, this is, for example, when the probability of selecting Lottery 2 is not equal to one despite the expected utility of Lottery 2 exceeding the expected utility of Lottery 1. With the inclusion of the Fechner error term: $\nabla EU = (EU_2 - EU_1)/\mu$ where μ is the Fechner noise parameter.

In addition, the "contextual error" specification developed by Wilcox (2011) and advocated by Harrison and Swarthout (2012) is incorporated into the model so that: $\nabla EU = ((EU_2 - EU_1)/v)/\mu$ where v is a normalising term which, for each lottery pair, is defined as the difference between the maximum and minimum utility over all lottery prizes in a particular lottery pair. Note that, as v is provided by the data, it is not a parameter that needs to be estimated.

With the inclusion of the Fechner error term (Hey and Orme 1994) and Wilcox's (2011) contextual error, the conditional log-likelihood is reflected as:

$$\ln L^{EUT}(r, \mu; y, X) = \sum [(\ln \Phi(\nabla EU_i) \times I(y_i = 1) + (\ln(1 - \Phi(\nabla EU_i)) \times I(y_i = 0))]$$

where r and μ are the parameters to be estimated.

Given the possibility of correlation between responses by the same subject, the standard errors are adjusted for clustering.

Cumulative Prospect Theory

Prospective utility is defined as:

$$PU_i = \sum_{k=1,4} [W_k \times u_k]$$

where

$W_i = \omega(p_i + \dots + p_n) - \omega(p_{i+1} + \dots + p_n)$ for $i = 1, \dots, n-1$, and

$W_i = \omega(p_i)$ for $i = n$, and

W_i is the subjective decision weight, p_i is the objective probability associated with lottery outcome x_i and $\omega(p)$ is some probability weighting function. Harrison and Swarthout (2012) provide a detailed discussion around calculating the subjective decision weights. In particular, while lottery prizes are rank ordered from best to worst in the gain frame, they are rank ordered from worst to best in the loss frame. In the mixed frame, lotteries are first separated into gain and loss-frame components and evaluated separately (the two positive prizes are rank ordered from best to worst and the two negative prizes are rank ordered from worst two best).

This experiment uses the probability weighting function suggested by TK (1992):

$$\omega(p) = \frac{p^{\gamma^+}}{(p^{\gamma^+} + (1-p)^{\gamma^+})^{1/\gamma^+}} \text{ for } x \geq 0$$

$$\omega(p) = \frac{p^{\gamma^-}}{(p^{\gamma^-} + (1-p)^{\gamma^-})^{1/\gamma^-}} \text{ for } x < 0$$

where, if $\gamma^{+/-} < 1$, the function exhibits an inverse S-shape reflecting overweighting of small probabilities and underweighting of large probabilities. Conversely, if $\gamma^{+/-} > 1$, the function is S-shaped, indicating underweighting of small probabilities and overweighting of large probabilities.

The TK weighting function is also compared to the Power weighting function: $\omega(p) = p^\gamma$ (Quiggin 1982) and the two-parameter Prelec weighting function: $\omega(p) = \exp\{-\eta - \ln p^\theta\}$ (Prelec 1998).

Following TK (1992) and using the CRRA utility specification, utility is defined separately over gains and losses:

$$U(x) = \frac{x^{1-\alpha}}{1-\alpha} \text{ when } x \geq 0$$

$$U(x) = -\lambda \left[\frac{(-x)^{1-\alpha}}{1-\alpha} \right] \text{ when } x < 0$$

where α is the risk aversion parameter, with $\alpha > 0$ implying concave utility for gains (risk aversion) and convex utility for losses (risk seeking); and where λ is the loss aversion parameter, with $\lambda > 1$ indicating loss aversion and $\lambda = 1$ indicating loss neutrality.

In estimating the parameters, the log-likelihood is the same as that reflected under the EUT specification; however, parameters α , λ , γ^+ , γ^- are to be estimated (instead of r), as well as the Fechner error term μ . Note that, when estimating CPT, “contextual utility” is not incorporated (Harrison and Swarthout 2012b).

Both the EUT and CPT models are estimated using maximum likelihood method using STATA.

5 Results

Relative to EUT, the CPT model allows for a more detailed breakdown of the various sources of risk aversion; specifically, in the CPT model: (i) probability weighting is incorporated, allowing objective probabilities to be transformed into subjective decision weights, thus enabling an assessment of the degree to which risk attitudes are attributed to probability weighting; and (ii) utility functions are defined separately over gains and losses, facilitating the identification of loss aversion (Harrison *et al.* 2010).

Table 3 reflects the results of the CPT model with no covariates. As $\alpha > 0$ ($\alpha = 0.277$, $p = 0.000$; CI: 0.198, 0.356), the model signals concavity of the value function over gains (risk aversion over gains), and convexity over losses (risk loving over losses).

Loss aversion is evident if $\lambda > 1$; however, while $\lambda = 1.247$ ($p = 0.000$; CI: 0.830, 1.664), the hypothesis that $\lambda = 1$ (hypothesis of loss neutrality) cannot be rejected ($p = 0.2456$), implying that losses do not loom larger than gains.

As γ^+ and γ^- are both significantly different from 1 ($p < 0.01$ in both the loss and gain frames), the data signal that participants transform objective probabilities into subjective decision weights. More specifically, $\gamma < 1$ implies that the probability weighting function has an inverse S-shape, characterised by a concave segment indicating the overweighting of small probabilities, a cross-over point where $\omega(p) = p$, and a convex section signalling underweighting of large probabilities (Andersen *et al.* 2010).¹⁰ Gonzalez and Wu (1999) and Tversky and Kahneman (1992) provide empirical support for an inverse S-shaped weighting function.

Figure 1 shows the estimated CPT probability weighting function and implied decision weights for gains and losses. Following Harrison and Swarthout (2012), decision weights are constructed for three reference lotteries: the 2-prize lottery has 2 prizes with a probability of $\frac{1}{2}$ each; the 3-prize lottery has 3 prizes each with a probability of $\frac{1}{3}$; in the 4-prize lottery, the prizes have a probability of $\frac{1}{4}$ each. With respect to the conversion of probability weights into decision weights, in the gain frame, where lottery prizes are presented from worst prize to best prize in figure 1, the decision weights place (marginally) greater weight on the worst outcome as compared to the best outcome, implying moderate risk aversion.¹¹ Conversely, in the loss frame, where lottery prizes are presented from best to worst prize, the decision weights place greater weight on the best outcome as opposed to the worst, implying moderate risk seeking.

The TK probability weighting function is compared to two alternatives – namely the Power and 2-parameter Prelec weighting functions (Quiggin 1982, Prelec 1998). These alternative probability weighting functions are illustrated in figure 2. The TK weighting function is consistent with the Prelec function, with the exception of low probabilities in the gain domain. The estimates for the conditional CPT model (with no covariates) with the Power and Prelec functions are provided in Appendix D. The estimates of risk and loss aversion are comparable between all three models. Specifically: $\alpha_{TK} = 0.277$, $\alpha_{Power} = 0.322$, $\alpha_{Prelec} = 0.247$; in all models, the hypothesis of loss neutrality cannot be rejected: $p_{TK} = 0.246$, $p_{Power} = 0.086$, $p_{Prelec} = 0.466$.

¹⁰ Note that we are not able to reject the null hypothesis that $\gamma^+ = \gamma^-$.

¹¹ For example, while the objective probability for each prize in the 4-prize case is 0.25, the decision weight for the worst prize is 0.3 as compared to 0.28 for the best prize. In the case of a linear utility function (with utility calculated using the decision weights), the certainty equivalent (CE) would be lower than the expected value (EV) (calculated using the true probabilities), signalling a positive risk premium and risk aversion (Harrison and Swarthout 2012).

Table 3. Estimates of CPT parameters

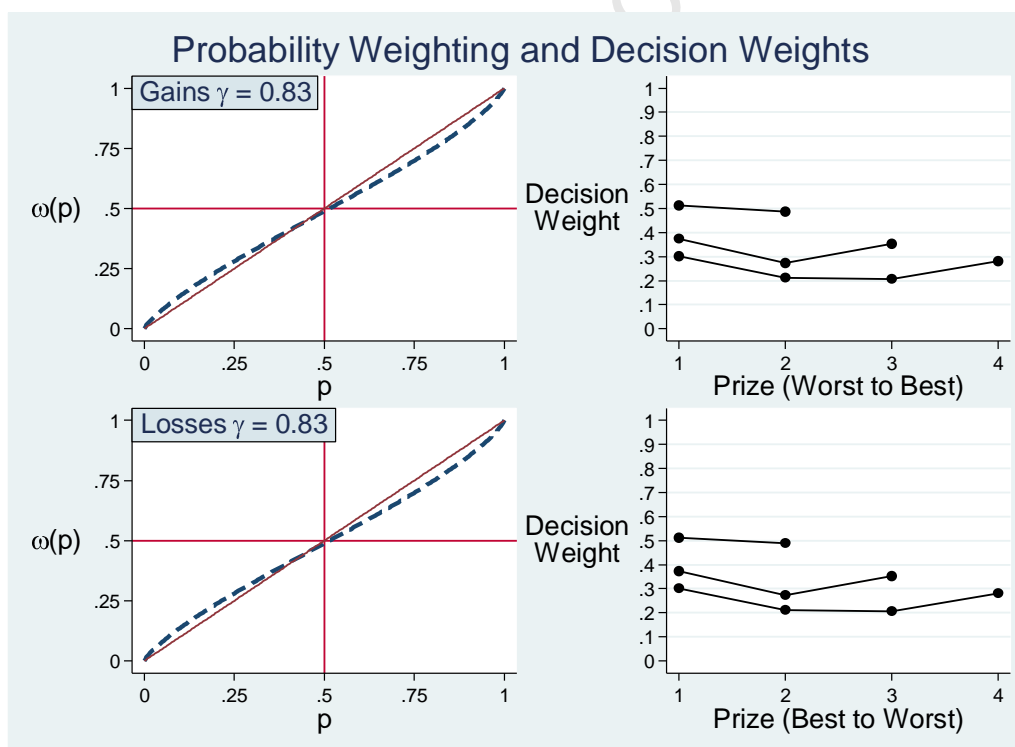
		Coef.	Robust Std. Err.	95% Conf. Interval	
$\alpha = \beta$:	Cons	0.2772**	0.0404	0.1981	0.3563
λ :	Cons	1.2470**	0.2127	0.8300	1.6639
γ^+ :	Cons	0.8333**	0.0417	0.7516	0.9149
γ^- :	Cons	0.8308**	0.0360	0.7601	0.9014
mu:	Cons	6.6739**	1.2526	4.2188	9.1290

$H_0: \lambda = 1$	$p = 0.2456$
$H_0: \gamma^+ = 1$	$p = 0.0001$
$H_0: \gamma^- = 1$	$p = 0.0000$
$H_0: \gamma^+ = \gamma^-$	$p = 0.9669$

Notes:

- * and ** signify significance at the 5% and 1% level, respectively
- Standard errors adjusted for clustering
- Estimated using TK (1992) probability weighting function
- Assume $\alpha = \beta$

Figure 1. Probability weighting function



Notes:

- Estimated using TK (1992) probability weighting function
- p refers to the probabilities presented to participants in a given lottery task while $\omega(p)$ is the weighted probability
- Decision weights calculated assuming lottery prizes of equal probability

Figure 2. Alternative probability weighting functions (conditional CPT model)

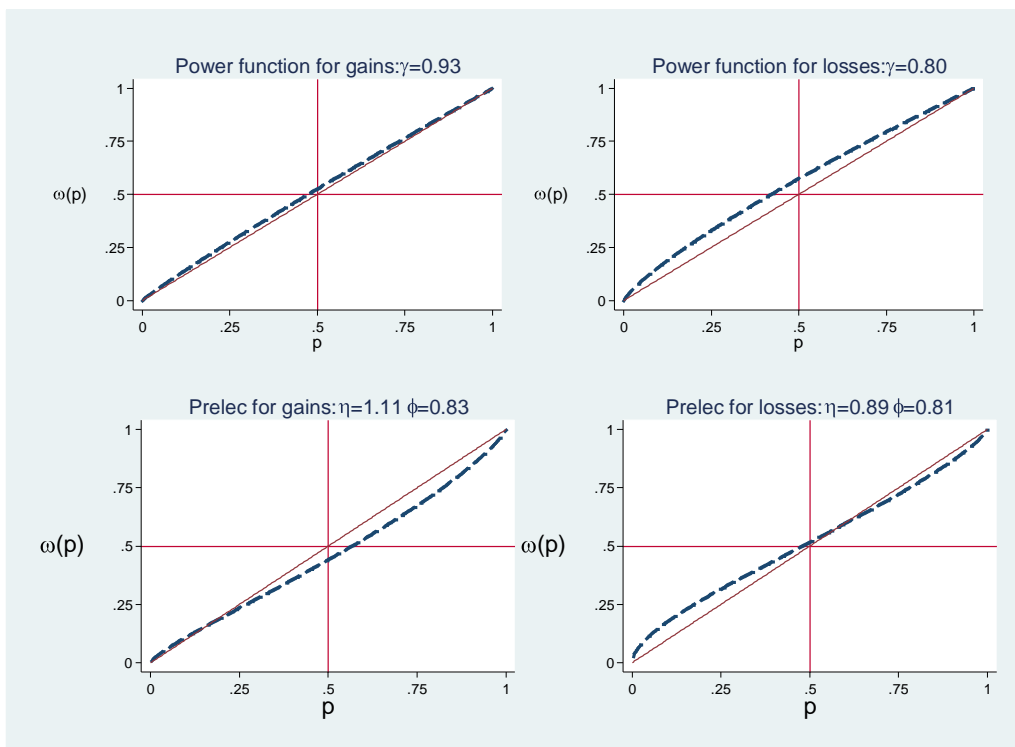


Table 4 reflects the CPT specification with covariates. Specifically, we include a number of dummy variables reflecting participants' demographic characteristics, including (i) gender (*Female*); (ii) level of education (*Grade-12*), denoting whether participants have received their final school-leaving certificate); (iii) age (with *Age* signalling if participants are over 40); and (iv) household income (where *HH income* equals to one if monthly household income is less than R2 000).

In addition, dummy variables reflecting participants' flood adaptation activities have also been incorporated into the model. Specifically, *Do nothing* equals one if a participant has done nothing to reduce damage from flooding; *Plastic sheeting* indicates if a participant has used plastic sheeting on his roof and/or floor (but has not raised his home above ground or slanted his roof); *Home above ground* signals whether a participant has used sandbags, stilts or pallets to raise his/her home above ground (participants may or may not also have used plastic sheeting on their roof); and, finally, the reference case is *Slanted roof*, which indicates whether a participant has slanted their roof to facilitate rainwater runoff (and in addition may or may not have raised his/her home above ground and used plastic sheeting). Both the cost and effectiveness of the adaptive strategy increase along the spectrum from “*Do nothing*” to

“*Slanted roof*”. Table 5 shows the overlap between adaptation strategies. Of the 33% of participants who have raised their home above ground, 40% use plastic sheeting on their roof, and 21% use plastic sheeting on their floor. Furthermore, of the 9% of participants who slant their roofs, 80% use plastic sheeting on their roof, 20% use plastic sheeting on their floor and 40% have raised their home above ground.

Finally, we include a dummy variable “*Flooding*” which captures participants’ experiences with flooding. Specifically, the variable equals one if the subject experienced flooding in the past two years. As expected, there is a degree of variation with respect to flood experience and uptake of adaptation strategies. Specifically, of those individuals opting to do nothing, use plastic sheeting, raise their home above ground and slant their roof, 53%, 88%, 88% and 93% have experienced flooding in the past two years.

The coefficients in table 4 are interpreted as the marginal effect of each variable as compared to the default case (Harrison *et al.* 2007). With respect to flood adaptation strategies, the results suggest that individuals opting for less effective strategies (relative to the most effective strategy of slanting one’s roof) are more risk seeking. In particular, for those individuals opting to do nothing (relative to those individuals who slant their roofs), RRA decreases by 0.542 ($p = 0.001$, CI: -0.851, -0.233). When correcting for this effect, RRA is estimated at 0.415 ($p = 0.005$ on the hypothesis of risk neutrality). In addition, RRA decreases by 0.619 ($p = 0.000$; CI: -0.816, -0.423) for those individuals relying solely on plastic sheeting; decreasing to 0.338 when correcting for this effect ($p = 0.003$). Finally, for those individuals who raise their homes above ground, RRA decreases by 0.535 ($p = 0.000$, CI: -0.705, -0.364). When correcting for this effect, RRA is estimated at 0.423 ($p = 0.000$).

There are significant differences in the extent of probability weighting for the adaptation strategies *Do nothing* and *Slant roof* in the gain frame (*Do nothing*: 0.452, $p = 0.030$; CI: 0.045, 0.859). Figure 3 presents the probability weighting function for these adaptation strategies. With respect to the decision weights reflected in the right hand panel of figure 3, it is evident that individuals who chose to slant their roofs, relative to those that opt to do nothing, exhibit a greater degree of risk aversion (whereby they place greater weight on the worst possible prize).

Table 4. Estimates of CPT parameters

		Coef.	Robust Std. Err.	95% Conf. Interval	
α	Cons	0.9572**	0.1281	0.7062	1.2082
	Female	0.0982	0.0641	-0.0275	0.2239
	Grade-12	-0.1409**	0.0527	-0.2441	-0.0377
	Age \geq 40	0.0305	0.0788	-0.1240	0.1849
	HH income \leq 2000	-0.0265	0.0605	-0.1451	0.0920
	Unemployed HH	-0.0948	0.0590	-0.2105	0.0209
	Do nothing	-0.5420**	0.1575	-0.8507	-0.2333
	Plastic sheeting	-0.6194**	0.1001	-0.8157	-0.4231
	Home above ground	-0.5345**	0.0869	-0.7048	-0.3643
	Flooding	-0.1036	0.1090	-0.3172	0.1099
λ	Cons	1.3853	0.7466	-0.0780	2.8486
	Female	0.5700	0.3807	-0.1762	1.3163
	Grade-12	0.2341	0.3168	-0.3868	0.8550
	Age \geq 40	-0.9155*	0.4169	-1.7326	-0.0983
	HH income \leq 2000	-0.2417	0.2904	-0.8108	0.3274
	Unemployed HH	-0.2482	0.2893	-0.8153	0.3189
	Do nothing	-0.6748	0.4928	-1.6408	0.2911
	Plastic sheeting	-0.4352	0.5511	-1.5154	0.6450
	Home above ground	0.0606	0.5371	-0.9921	1.1134
	Flooding	-0.1766	0.3310	-0.8254	0.4722
γ (gains)	Cons	0.5653*	0.2871	0.0027	1.1280
	Female	0.0097	0.0994	-0.1851	0.2046
	Grade-12	-0.0659	0.0914	-0.2449	0.1132
	Age \geq 40	-0.0779	0.1134	-0.3001	0.1443
	HH income \leq 2000	-0.0479	0.1091	-0.2617	0.1659
	Unemployed HH	-0.1451	0.0886	-0.3188	0.0286
	Do nothing	0.4521*	0.2077	0.0450	0.8592
	Plastic sheeting	0.1825	0.1886	-0.1872	0.5521
	Home above ground	0.1493	0.1801	-0.2038	0.5024
	Flooding	0.1887	0.1397	-0.0850	0.4624
γ (losses)	Cons	0.8396**	0.2682	0.3139	1.3652
	Female	-0.0481	0.0918	-0.2281	0.1319
	Grade-12	-0.0673	0.1117	-0.2862	0.1516
	Age \geq 40	-0.4146*	0.1711	-0.7500	-0.0792
	HH income \leq 2000	0.0501	0.0869	-0.1203	0.2204
	Unemployed HH	1.8362**	0.4505	0.9533	2.7192
	Do nothing	-0.2619	0.1451	-0.5463	0.0225
	Plastic sheeting	0.2946	0.1871	-0.0722	0.6613
	Home above ground	0.2555	0.1322	-0.0036	0.5145
	Flooding	-0.1944	0.1690	-0.5257	0.1368
μ	Cons	6.4963*	1.5059	3.5447	9.4479

Notes:

- * and ** signify significance at the 5% and 1% level, respectively
- Standard errors adjusted for clustering
- Estimated using TK (1992) probability weighting function

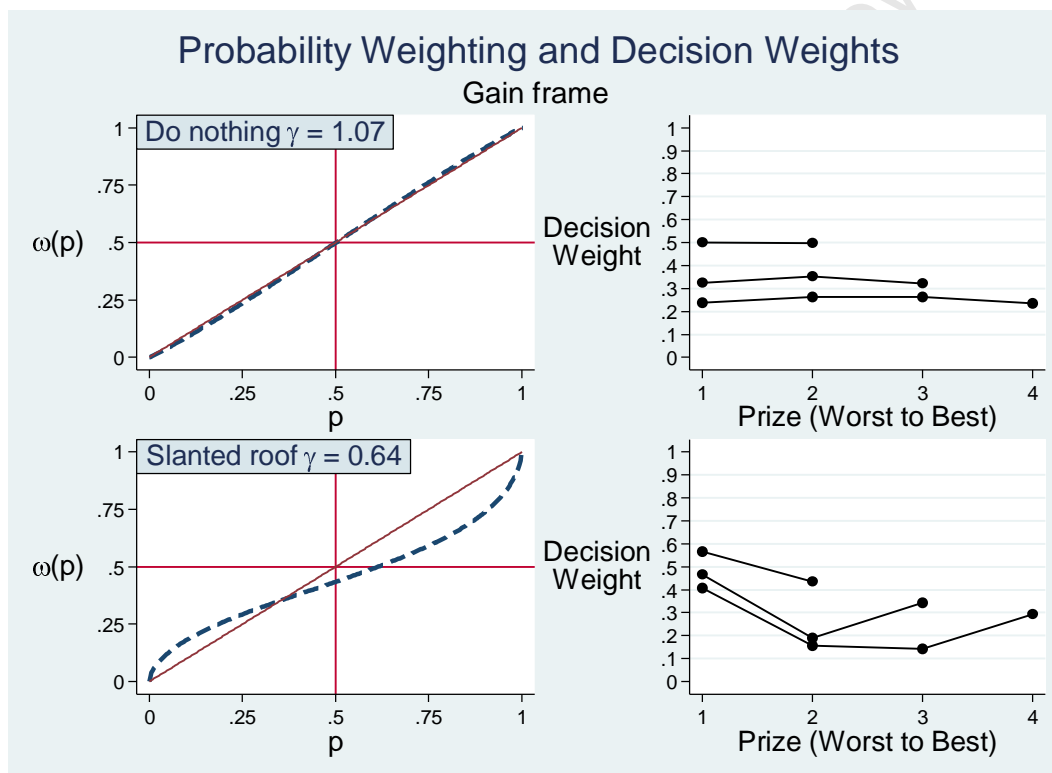
Table 5. Adaptation strategies

Primary adaptation strategy	% of sample	Plastic sheeting on roof % of subsample	Plastic sheeting on floor % of subsample	Home above ground % of subsample
Do nothing	0.10	0.00	0.00	0.00
Plastic sheeting	0.28	0.90	0.21	0.00
Home above ground	0.33	0.40	0.21	1.00
Slant roof	0.09	0.80	0.20	0.40

Notes:

- Plastic sheeting refers to use of plastic sheeting on roof and/or floors
- Read table as follows: 33% of the sample raise their home above ground. Of these participants, 40% use plastic sheeting on their roof, 21% use plastic sheeting on their floor (and obviously 100% raise their home above ground)

Figure 3. Probability weighting functions for selected adaptation strategies



Note: Estimated using TK (1992) probability weighting function

For comparative purposes, the parameter estimates of an EUT model (also assuming a CRRA utility function) are provided in Appendix E. As appears from Panel A in table E1, which reflects the results of the EUT model with no covariates, RRA is estimated to be -0.070; however, the coefficient is not significantly different from zero, indicating a scenario of risk neutrality ($p = 0.441$; CI: -0.247, 0.108). This result is surprising, given that estimates found in

the literature across different samples generally indicate moderate levels of risk aversion (Holt and Laury 2002, Harrison and Rutström 2009 and Harrison *et al.* 2010).¹²

As previously mentioned, EUT assumes local asset integration in terms of which individuals evaluate net gains and losses. In contrast, CPT assumes that individuals do not locally asset-integrate but rather evaluate gross gains and losses (Harrison and Swarthout 2012). The results from the CPT model (when estimating without asset integration) indicate a utility function that is concave over gains and convex over losses. Additionally, the probability weighting functions likewise imply risk aversion in gains and risk seeking in losses. The implication is that, in the event of assuming no probability weighting, this dynamic should be absorbed into the utility function, thus exaggerating the curvature further. However, the utility function under the EUT specification, which assumes asset integration and does not allow for probability weighting, is essentially linear. As such, the assumption of asset-integration is the most likely driver of the differences between the EUT and CPT models.¹³

Panel B in table E1 reflects the result of the model when including the familiar explanatory variables. In addition, dummy variables reflecting the treatment frame are incorporated into the model (*Gain frame*, *Mixed frame* and *Loss frame*, with *Gain frame* as the reference case). With respect to flood adaptation, the results are in broad consensus with the CPT model, implying that individuals relying on plastic sheeting and choosing to raise their home above ground are less risk averse relative to individuals that slant their roofs; however, these results are only significant at the 10% level. More specifically, for those individuals relying solely on plastic sheeting, RRA decreases by 0.540 ($p = 0.058$, CI: -1.098, 0.018), and individuals who raise their homes above ground exhibit less risk aversion relative to those that slant their roofs ($p = 0.099$, CI: -0.719, 0.061).

¹² As mentioned above, in the context of the sample setting being an extremely low-income community, participants' choice of adaptation strategy can have significant financial implications; conversely, experimental elicitation of risk preferences are constrained in terms of the income variations that are able to be simulated (we thank an anonymous reviewer for this point). Consequently, the risk neutrality evident in the EUT model could reflect the fact that the experimental payoffs did not simulate sufficient income variations to reveal the true risk parameter. While this limitation must be acknowledged, we do find evidence of utility risk aversion (over gains) and utility risk seeking (over losses) in the CPT model. By incorporating probability weighting, the CPT model allows for a more detailed breakdown of the various sources of risk aversion. More specifically, the incorporation of probability weighting provides another way in which individuals can exhibit risk aversion that is distinct from the risk aversion synonymous with the concavity of the utility function (Andersen et al. 2010).

¹³ We thank an anonymous reviewer for making this point.

In terms of a comparison of the EUT and CPT non-nested models, we would anticipate that the CPT model is the preferred model, given the inference of probability weighting from the CPT parameter estimates. Following Andersen *et al.* (2010), Harrison and Rutström (2009) and Harrison (2008), we apply the Vuong (1989) and Clarke (2003) tests to the EUT and PT models (with no covariates). Both tests favour the CPT model over the EUT model (Vuong test statistics: -10.49 and favours EUT if positive; Clarke test statistic: 4586 and favours EUT if greater than 5250).¹⁴

6 Discussion

Developmental economists are concerned with the extent to which individual risk preferences are linked with economic success (Tanaka *et al.* 2010). An example of this (albeit one unrelated to flooding) is the poverty-trap hypothesis, which posits that without insurance as a safety net, risk-averse individuals might be reluctant to invest in riskier but potentially more profitable activities (Dercon 2005). However, while there is a large literature addressing the estimation of risk preferences in developed and developing countries, comparatively fewer papers consider the extent to which estimated risk preferences are correlated with observed behaviour.

Against this background, this study characterises the risk attitudes of a sample of individuals living in a flood-prone urban informal settlement in South Africa, and considers the extent to which risk attitudes are correlated with choice of flood adaptation strategy.

The observed risk attitudes of this low-income community and, more particularly, the relationship between risk attitudes and flood adaptation, are particularly interesting, given that decisions around flood adaptation involve significant stakes. In particular, vulnerability to flood risk (and the financial loss and diminished wellbeing associated with flood damage to immovable property and possessions) are determined, in part, by choices regarding how to mitigate the risk of damage from flooding (in other words, choice of adaptation strategy). While there are a number of adaptation strategies that participants can implement in a bid to reduce their exposure to flood risk, there is significant variation in individuals' efforts to adapt.

¹⁴ Note that the Vuong and Clarke tests are premised on the assumption that only one of the models is the true model whereas a "mixture model approach" allows for heterogeneity in decision making, such that subjects' choices are not best represented by one single theory (Harrison and Rutström 2009; Harrison *et al.* 2010).

The results signal a correlation between risk aversion and adaptation strategies undertaken. Adaptation strategies incorporated into the model are classified from least effective [(i) do nothing or (ii) rely solely on plastic sheeting] to most effective [(iii) raise your home above ground or (iv) slant your roof].

The CPT model indicates that adaptation strategies are correlated with risk preferences. Specifically, the results indicate that individuals that (i) do nothing, (ii) rely solely on plastic sheeting or (iii) raise their homes above ground, are less risk averse relative to individuals who slant their roofs to assist rainwater runoff.

This result implies that attempts by local authorities to encourage uptake of adaptation strategies must take into account risk attitudes (as opposed to assuming risk neutrality on the part of the decision maker). More specifically, given the level of variation in individual adaptation efforts, city officials might supplement ongoing education initiatives with proactive measures to incentivise even risk-seeking individuals to engage with adaptation (for example, through the provision of a subsidy on building materials).

More generally, while risk preferences are often considered within very specific contexts – for example in applications to addiction, the result of this study indicates that attitudes toward risk impact on individual decision-making (and therefore welfare outcomes) within the wider framework of our daily decision-making.

References

- Alpizar, F., Carlsson F., Naranjo, M., 2011, "The Effect of Ambiguous Risk and Coordination on Farmers' Adaptation to Climate Change: A Framed Field Experiment." *Ecological Economics*, 70:2317 - 2326.
- Andersen, S., Harrison, G., Lau, M., Rutström, E., 2008, "Eliciting Risk and Time Preferences." *Econometrica*, 76:583 - 618.
- Andersen, S., Harrison, G., Lau, M., Rutström, E., 2010, "Behavioral Econometrics for Psychologists." *Journal of Economic Psychology*, 31:553 - 576.
- Andersen, S., Harrison, G., Hole, A., Lau, M., Rutström, E., 2012, "Non-Linear Mixed Logit." *Theory and Decision*, 73(1): 77-96.
- Andreoni, J., Sprenger, C., 2011, "Uncertainty Equivalents: Testing the Limits of the Independence Axiom." National Bureau of Economic Research Working Paper 17342.
- Barr, A., 2003, "Risk Pooling, Commitment, and Information: An Experimental Test of Two Fundamental Assumptions." Centre for Study of African Economies Working Paper Series, 2003-05.
- Binswanger, H., 1980, "Attitudes toward Risk: Experimental Measurement in Rural India." *American Journal of Agricultural Economics*, 62(3):395 – 407.
- Bouchard, B., Goncalo, A., Susienka, M., Wilson, K., 2007, "Improving flood risk management in informal settlements of Cape Town." Worcester Polytechnic Institute.
- Chirwa, E., 2005, "Adoption of fertiliser and hybrid seeds by smallholder maize farmers in Southern Malawi." *Development Southern Africa*, 22(1): 1-12.
- City of Cape Town, 2005, "Study on the social profile of residents of three selected informal settlements." Cape Town: City of Cape Town

City of Cape Town, 2009, "Winter Preparedness Strategy." Document number SMC 05/03/09.

Clarke, K., 2003, "Nonparametric Model Discrimination in International Relations." *Journal of Conflict Resolution*, 47(1): 72-93.

Cox, J., Sadiraj, V., Schmidt, U., 2014, "Asymmetrically Dominated Choice Problems, the Isolation Hypothesis and Random Incentive Mechanisms." *PLoS ONE* 9(3): e90742.

Cox, J., Sadiraj, V., Schmidt, U., 2014a, "Alternative Payoff Mechanisms for Choice under Risk." *Kiel Working Papers* No. 1932.

Croppenstedt, A., Demeke, M., Meschi, M., 2003, "Technology Adoption in the Presence of Constraints: the Case of Fertiliser Demand in Ethiopia." *Review of Development Economics*, 7(1): 58-70.

Dercon, S., 2005, "Risk, Poverty and Vulnerability in Africa." *Journal of African Economies*, 14(4): 483-488.

Dercon, S., Christiaensen, L., 2011, "Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia." *Journal of Development Economics*, 96: 159-173.

Eckel, C., Grossman, P., 2002, "Sex Differences and Statistical Stereotyping in Attitudes Toward Financial Risk." *Evolution and Human Behavior*, 23:281 – 295.

Eckel, C., Grossman, P., 2008, "Forecasting Risk Attitudes: An Experimental Study Using Actual and Forecast Gamble Choices." *Journal of Economic Behavior and Organization*, 68:1 – 17.

Engle-Warnick, J., Escobal, J., Laszlo, S., 2007, "Ambiguity Aversion as a Predictor of Technology Choice: Experimental Evidence from Peru." *CIRANO Scientific Series*, 2007s-01.

Fennema, H., Wakker, P., 1997, "Original and Cumulative Prospect Theory: A Discussion of Empirical Differences." *Journal of Behavioral Decision Making*, 10: 53 – 64.

- Galarza, F., 2009, "Choices under Risk in Rural Peru." MPRA Paper No. 17708.
- Gonzalez, R., Wu, G., 1999, "On the Shape of the Probability Weighting Function." *Cognitive Psychology*, 38: 129-166.
- Harbaugh, W., Krause, K., Vesterlund, L., 2009, "The Fourfold Pattern of Risk Attitudes in Choice and Pricing Tasks." *The Economic Journal*, 120: 595–611.
- Harrison, G., 2008, "Maximum Likelihood Estimation of Utility Functions Using Stata," Working Paper 06-12, Department of Economics, College of Business Administration, University of Central Florida.
- Harrison, G., Rutström, E., 2008, "Risk Aversion in the Laboratory." *Research in Experimental Economics*, 12:41 – 196.
- Harrison, G., Rutström, E., 2009, "Expected Utility Theory and Prospect Theory: One Wedding and a Decent Funeral." *Experimental Economics*, 12:133-158.
- Harrison, G., Lau, M., Rutström, E., 2007, "Estimating Risk Attitudes in Denmark: A Field Experiment." *Scandinavian Journal of Economics*, 109(2): 341-368.
- Harrison, G., Humphrey, S., Verschoor, A., 2010, "Choice under Uncertainty: Evidence from Ethiopia, India and Uganda." *The Economic Journal*, 120:80 – 104.
- Harrison, G., Swarthout, T., 2012, "Loss Frames in the Laboratory."
- Harrison, G., Swarthout, T., 2012a, "The Independence Axiom and the Bipolar Behaviorist." Georgia State University ExCEN Working Papers Series.
- Hey, J., Orme, C., 1994, "Investigating Generalizations of Expected Utility Theory Using Experimental Data." *Econometrica*, 62(6): 1291-1326.

- Holloway, A., Roomaney, R., Pharaoh, R., Solomon, F., Cousins, D., 2008, "Weathering the Storm: Participatory risk assessment for informal settlements." Disaster Mitigation for Sustainable Livelihoods Programme, University of Cape Town.
- Holt, C., Laury, S., 2002, "Risk Aversion and Incentive Effects." *The American Economic Review*, 92(5):1644 – 1655.
- Humphrey, S., Verschoor, A., 2004a, "Decision-making Under Risk Among Small Farmers in East Uganda." *Journal of African Economies*, 13(1):44 – 101.
- Humphrey, S., Verschoor, A., 2004b, "The Probability Weighting Function: Experimental Evidence from Uganda, India and Ethiopia." *Economic Letters*, 84:419 – 425.
- Kahneman, D., Tversky, A., 1979, "Prospect Theory: An Analysis of Decision under Risk." *Econometrica*, 47(2):263-291.
- Liu, E., 2008, "Time to Change What to Sow: Risk Preferences and Technology Adoption Decisions of Cotton Farmers in China." Princeton University Working Paper No. 526.
- Mosley, P., Verschoor, A., 2005, "Risk Attitudes and the Vicious Circle of Poverty." *The European Journal of Development Research*, 17: 1, 59 — 88.
- Mukheibir, P., Ziervogel, G., 2006, "Framework for Adaptation to Climate Change in the City of Cape Town. City of Cape Town: Environment Resource Management.
- Olorunfemi, F., 2010, "Climate Change and Flood Risk in the Informal Settlements of Cape Town: Understanding Vulnerability and Adaptation Options." Final Technical Report, Climate Systems Analysis Group, University of Cape Town.
- Prelec, D., 1998, "The Probability Weighting Function." *Econometrica*, 66: 497-527.
- Quiggin, J., 1982, "A Theory of Anticipated Utility." *Journal of Economic Behavior & Organization*, 3(4):323-343.

- Simtowe, F., 2006, "Can Risk-aversion towards fertiliser explain part of the non-adoption puzzle for hybrid maize? Empirical evidence from Malawi." MPRA Paper No. 1241.
- Tanaka, T., Camerer, C., Nguyen, Q., 2010, "Risk and Time Preferences: Linking Experimental and Household Survey Data from Vietnam." *American Economic Review*, 100(1):557 – 571.
- Tversky, A., Kahneman, D., 1992, "Advances in Prospect Theory: Cumulative Representations of Uncertainty." *Journal of Risk & Uncertainty*, 5: 297-323.
- Vuong, Q., 1989, "Likelihood Ratio Tests for Model Selection and Non-Nested Hypotheses." *Econometrica*, 57(2): 307-333.
- Wik, M., Kebede, T., Bergland, O., Holden, S., 2004, "On the Measurement of Risk Aversion from Experimental Data." *Applied Economics*, 36:2443 – 2451.
- Wilcox, N., 2011, "Stochastically More Risk Averse: A Contextual Theory of Stochastic Discrete Choice Under Risk." *Journal of Econometrics*, 162(1): 89-104.
- Yesuf, M., Bluffstone, R., 2009, "Poverty, Risk Aversion, and Path Dependence in Low-Income Countries: Experimental Evidence from Ethiopia." *American Journal of Agricultural Economics*, 91(4):1022 – 1037.
- Ziervogel, G., Smit, W., 2009, "Learning to swim: Strengthening flooding governance in the City of Cape Town." Working Paper for the 2009 Amsterdam Conference on the Human Dimensions of Global Environmental Change 'Earth System Governance: People, Places and the Planet'.

Appendix A. Experiment design

Table A1. Experiment design: lottery probabilities

	Lottery 1				Lottery Option 2			
Gain frame	R0	R50	R100	R150	R0	R50	R100	R150
Mixed frame	-R150	-R100	-R50	R0	-R150	-R100	-R50	R0
Loss frame	-R75	-R25	R25	R75	-R75	-R25	R25	R75
Lottery task:	Prob. 1	Prob. 2	Prob. 3	Prob 4.	Prob. 1	Prob. 2	Prob. 3	Prob. 4
1	0.13	0.00	0.25	0.62	0.00	0.00	1.00	0.00
2	0.13	0.38	0.49	0.00	0.00	1.00	0.00	0.00
3	0.00	0.00	0.62	0.38	0.13	0.00	0.13	0.74
4	0.00	0.87	0.13	0.00	0.13	0.62	0.25	0.00
5	0.87	0.00	0.00	0.13	0.75	0.25	0.00	0.00
6	0.13	0.87	0.00	0.00	0.37	0.37	0.00	0.26
7	0.13	0.87	0.00	0.00	0.25	0.50	0.25	0.00
8	0.38	0.00	0.00	0.62	0.25	0.00	0.75	0.00
9	0.37	0.26	0.37	0.00	0.25	0.62	0.13	0.00
10	0.25	0.75	0.00	0.00	0.38	0.00	0.62	0.00

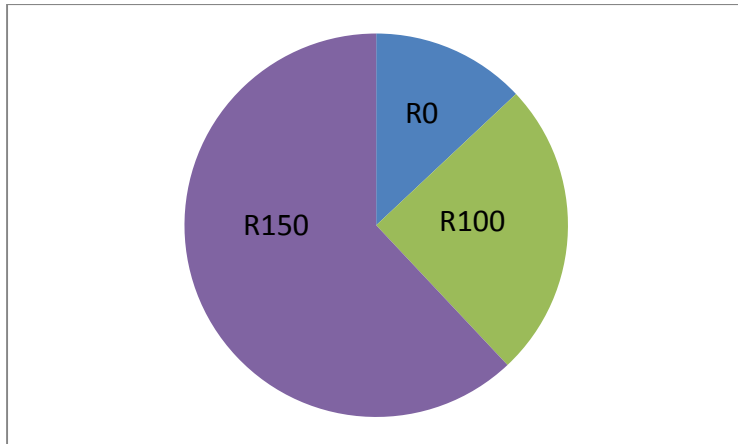
Source: Harrison and Rutström (2009)

Appendix B. Experiment procedures

Figure B1. Decision sheet, lottery task 1, gain frame

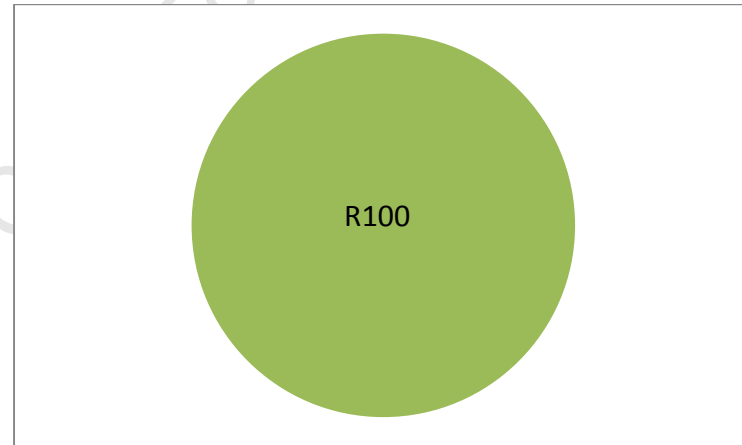
Lottery 1:

R0	R50	R100	R150
13%	0%	25%	62%



Lottery 2:

R0	R50	R100	R150
0%	0%	100%	0%



Appendix C. Experiment instructions (loss frame)

Introduction

Good morning! Thank you for coming. My name is [NAME], and I am a researcher with the University of Cape Town. These are my colleagues [NAMES]. We have invited you here to play some financial games.

You will be paid for participating in this workshop today. For being here today you will earn R50. This is your money to take home.

We are going to start by filling out a short survey. You will earn money for filling in this survey. You will earn R300 for filling in this survey.

Now this is very important. Let me repeat: this is VERY important. When we play the financial games, **you can lose money**. Any money that you lose will be deducted from this R300 that you have earned for filling in the survey. You could **lose some or all** of this R300 during the day. Remember that any money that you lose while we play the games will be deducted from this R300.

How much money you lose depends on the decisions you make during the games. That is why it is very important you understand the rules of the games, which I am going to explain to you as we go along.

The income you earn from today will be paid to you at the end of the day in the form of a cash cheque which you can cash at any branch of ABSA Bank.

You play these games as individuals, not in groups. So please don't talk to anyone while we are playing the games. If you have any questions at any stage you can just raise your hand and someone will come and answer your question privately.

Participation in these sessions is voluntary. If you decide not to take part, you may leave at any moment, even after you have started playing – but then you will not earn any money. If you prefer to stay we ask that you sign the form that our assistants are bringing around right now.

[HAND OUT THE CONSENT FORMS]

This form says that you understand participation in these games is voluntary and that you can leave whenever you want to. But if you do leave before we have finished playing all the games, you won't receive any money.

Is everyone finished signing the forms? Ok, someone is going to come around and collect the forms from you.

[COLLECT FORMS]

Part 1

As I said, we are going to start by filling out a short survey...

Remember, you will earn R300 for filling in this survey.

[Hand out the surveys]

[Collect the surveys once everyone has completed them]

Part 2

Let's move on to the financial games.

Remember, you can **lose money** by playing these games. **Any money that you lose will be deducted from the R300 that you have earned for filling in the survey.**

I am now going to explain the rules of the game.

Let's start with the first game in the booklet: Game 1

GAME 1

This poster is a large version of the sheet of paper that is in front of you.

In this game, you must choose between 2 options: Option 1 and Option 2 [REFER TO POSTER].

You must show on the sheet in front of you, whether you choose Option 1 or Option 2.

Now, for both of these options, for Option 1 and Option 2, the amount of money you **lose** depends on these spinning wheels. And, it depends on what colour the arrow lands on.

On this spinning wheel we have option 1. And on this spinning wheel we have option 2.

Option 1.

[Hold the spinning wheel underneath the poster]

As you can see, in option 1, the arrow can land on blue, green or purple [rotate the spinning wheel while you talk]

[Point to the poster]

If the arrow lands on blue, you lose R150

If the arrow lands on green, you lose R50

If the arrow lands on purple, you lose nothing

These blocks [point to the row of coloured blocks on the poster] **also** tell you how much money you would **lose** if the arrow lands on blue, purple or green:

If the arrow lands on blue, you lose R150

If the arrow lands on red you lose R100 – **but there is no red in this game**

If the arrow lands on green, you lose R50,

And if the arrow lands on purple, you lose nothing.

There are two ways you can think about Option 1.

The first way is to use the percentages that are shown in this row [point]. With Option 1, there is a 13% chance that you will lose R150. There is a 25% chance that you will lose R50. There is a 62% chance that you will lose nothing.

The other way to think about Option 1 is to look at the different sizes of the coloured areas. **This is the way that we are going to explain the games to you.**

The purple area is MUCH bigger than both the green and blue areas. So this means that if you choose Option 1, there is a much bigger chance of the arrow landing on purple and you losing nothing than there is of the arrow landing on blue and green.

Now look at the green area. This is slightly bigger than the blue area. So at least you know there is a slightly bigger chance of the arrow landing on green than there is of the arrow landing on blue. So you have a slightly bigger chance of losing R50 than you do of losing R150.

But even though the blue area is small – it is still there. So there is a small chance the arrow could land on blue and you could lose R150.

Now let's look at Option 2.

As you can see, in option 2, the arrow can only land on green because the whole area is green [rotate the spinning wheel while you talk]

[Hold the spinning wheel under the poster]

[Point to the poster]

If the arrow lands on green, you lose R50

These blocks [point to the row of coloured blocks on the poster] **also** tell you how much money you would lose if the arrow lands on green:

If the arrow lands on blue, you lose R150 – **but there is no blue in this game**

If the arrow lands on red you lose R100 – **but there is no red in this game**

If the arrow lands on green, you lose R50

And if the arrow lands on purple, you lose nothing – **but there is no purple in this game**

So the arrow can only land on green. **That means with Option 2 you are sure to lose R50.**

So now, you have to decide if you want to choose Option 2 and know that you will lose R50 for sure, or if you want to choose Option 1 – where there is a big chance you will lose nothing but a small chance you will lose R150.

Let's do an example. Let's pretend that I am the type of person that wants to pick Option 1. Then I would show this by making a tick next to Option 1 [make a tick next to option 1]. Now that I have chosen Option 1, we spin the wheel so that I can see how much money I would lose. [Spin the wheel]. Ok, so the arrow has landed on [blue, green, purple] which means that I would have lost [R150, R50, R0].

GAME 2

Ok, let's look at the second game. Once again, you must show on the sheet in front of you, whether you choose Option 1 or Option 2.

Now, for both of these options, for Option 1 and Option 2, the amount of money you lose depends on these spinning wheels. And, it depends on what colour the arrow lands on.

On this spinning wheel we have option 1. And on this spinning wheel we have option 2.

Option 1.

As you can see, in option 1, the arrow can land on red, blue or green

[Rotate the spinning wheel while you talk]

[Hold the spinning wheel under the poster]

[Point to the poster]

If the arrow lands on red, you lose R100

If the arrow lands on green, you lose R50

If the arrow lands on blue, you lose R150

Remember, these blocks [point to the row of coloured blocks on the poster] **also** tell you how much money you would get **lose** the arrow lands on red, green and blue:

If the arrow lands on blue, you lose R150

If the arrow lands on red you lose R100

If the arrow lands on green, you lose R50

And if the arrow lands on purple, you lose nothing – **but there is no purple in this game.**

The green area is a bit bigger than the red area and MUCH bigger than the blue area. So this means that if you choose Option 1, there is a bigger chance of the arrow landing on green and you losing R50 than there is of the arrow landing on red or blue.

But the red area is still quite big. So there is still a big chance of the arrow landing on red and of you losing R100.

Even though the blue area is very small, there is still a small chance that the arrow could land on blue and then you could lose R150.

Option 2

As you can see, in option 2, the arrow can only land on red because the whole area is red [rotate the spinning wheel while you talk]

[Hold the spinning wheel under the poster]

[Point to the poster]

If the arrow lands on red, you lose R100

These blocks [point to the row of coloured blocks on the poster] **also** tell you how much money you would lose if the arrow lands on red:

If the arrow lands on blue, you lose R150 – **but there is no blue in this game**

If the arrow lands on red you lose R100

If the arrow lands on green, you lose R50 – **but there is no green in this game**

And if the arrow lands on purple, you lose nothing – **but there is no purple in this game.**

So the arrow can only land on red. **That means with Option 2 you are sure to lose R100.**

So now, you have to decide if you want to choose Option 2 and lose R100 for sure, or if you want to choose Option 1 and maybe only lose R50. But remember, with Option 1, there is still a small chance of you losing R150.

Let's do an example. Let's pretend that I am the type of person that wants to pick Option 2. Then I would show this by making a tick next to Option 2. With Option 2, I know that I will lose R100 for sure so there is no need to spin the wheel. But let's spin it anyway [spin the wheel]. OK the arrow landed on red and I lose R100.

GAME 3

Let's look at the third game. Once again, you must show on the sheet in front of you, whether you choose Option 1 or Option 2.

On this spinning wheel we have option 1. And on this spinning wheel we have option 2.

Option 1.

As you can see, in option 1, the arrow can land on green or purple [rotate the spinning wheel while you talk]

[Hold the spinning wheel under the poster]

[Point to the poster]

If the arrow lands on green, you lose R50

If the arrow lands on purple, you lose nothing

The green area is quite a bit bigger than the purple, so if you choose this option, there is a bigger chance of you losing R50 than there is of you losing nothing. But the purple area is still quite big – so there is still a large chance of you losing nothing. But the worst you can do in this option, is lose R50.

Option 2.

As you can see, in option 2, the arrow can land on purple, green or blue [rotate the spinning wheel while you talk]

[Hold the spinning wheel under the poster]

[Point to the poster]

If the arrow lands on purple, you lose nothing

If the arrow lands on green, you lose R50

If the arrow lands on blue, you lose R150

The purple area is very large. So if you choose this option, there is a very large chance that the arrow will land on purple and that you will lose nothing.

Even though the green and blue areas are very small, they are still there. So there is still a small chance the arrow will land on green and you will lose R50 and a small chance the arrow will land on blue and you will lose R150.

So now, you have to decide if you want to choose Option 1 – where the worst you can do is lose R50, or if you want to choose Option 2, where there is a big chance you will lose nothing but there is a small chance you will lose R150.

Let's do an example. Let's pretend that I am the type of person that wants to pick Option 2. Then I would show this by making a tick next to Option 2. Now that I have chosen Option 2, we spin the wheel so that I can see how much money I would earn. [Spin the wheel]. Ok, so the arrow has landed on [blue, green, purple] which means that I would have lost [R150, R50, R0].

[Conclude:]

Are there any questions so far?

Soon I am going to ask you to go through the booklet yourself. And on each page, I want you to decide whether you would like to play Option 1 or Option 2.

Before you do that I want to explain one last thing:

In this booklet there are 60 games. You are going to fill in the booklet for all 60 games. But we won't have time to play all 60 games. So at the end of the day, we will choose 2 games to play for money.

But we don't know which of these 60 games we will be playing for money.

I have here 60 pieces of paper – numbered 1-60. I am going to put these pieces of paper in this bag. At the end of the day, 2 of you will each pull a piece of paper out the bag.

Whichever numbers are pulled out the bag – those are the games we will play.

So if number 1 is pulled out the bag, we will play game 1 for money, if number 20 is pulled out the bag, we will play game 20 for money. Let's do a demonstration [pull a number out of the bag]... **so, because we don't know which of the 60 games we will be playing for real money, it is important to act as if every game is being played for real money.**

Now you can go through the booklet yourself. And on each page, I want you to decide whether you would like to play Option 1 or Option 2.

Remember that any money that you lose will be deducted from the R300 that you have earned for filling in the survey.

When everyone is finished, we will use these numbered pieces of paper to decide which 2 games we are going to play for money.

Univeristy of Cape Town

Appendix D. Alternate CPT models

Table D1. CPT model with alternate probability weighting functions

		Coef.	Robust Std. Err.	95% Conf. Interval	
Panel A: CPT model with the Power probability weighting function					
α :	Cons	0.3215**	0.0297	0.2633	0.3798
λ :	Cons	1.3188**	0.1855	0.9553	1.6824
γ^+ :	Cons	0.9281**	0.0675	0.7958	1.0603
γ^- :	Cons	0.8005**	0.0625	0.6780	0.9231
mu:	Cons	5.1652**	0.8120	3.5738	6.7567
$H_0: \lambda = 1$		$p = 0.0857$			
$H_0: \gamma^+ = 1$		$p = 0.2864$			
$H_0: \gamma^- = 1$		$p = 0.0014$			
$H_0: \gamma^+ = \gamma^-$		$p = 0.1582$			
Panel B: CPT model with the Prelec weighting function					
α :	Cons	0.2474**	0.0348	0.1792	0.3156
λ :	Cons	1.1106**	0.1515	0.8136	1.4076
η^+ :	Cons	1.1069**	0.0634	0.9826	1.2311
η^- :	Cons	0.8858**	0.0578	0.7724	0.9992
Φ^+ :	Cons	0.8275**	0.0378	0.7534	0.9015
Φ^- :	Cons	0.8053**	0.0456	0.7159	0.8946
mu:	Cons	5.8162	0.9390	3.9757	7.6567
$H_0: \lambda = 1$		$p = 0.4656$			

Appendix E. EUT model

Panel A in table E1 reflects the results of the EUT model with no covariates. For the CRRA expected utility specification, $r < 0$ denotes risk-loving behaviour, $r = 0$ indicates risk neutrality and $r > 0$ denotes risk aversion (Harrison *et al.* 2010). As evident from Table 3, RRA is estimated to be -0.070, however the coefficient is not significantly different from zero indicating risk neutrality ($p = 0.441$; CI: -0.247, 0.108). Estimates found in the literature across different samples generally indicate moderate levels of risk aversion: Holt and Laury (2002) and Harrison and Rutström (2009) for American university students; and, in a developing-country context, Harrison *et al.* (2010) estimate a CRRA coefficient of 0.536 from experiments conducted in Ethiopia, India and Uganda (note lottery tasks are restricted to the gain frame).

Panel B in table E1 reflects the result of the model including the familiar explanatory variables. In addition, dummy variables reflecting the treatment frame are incorporated into the model (*Gain frame*, *Mixed frame* and *Loss frame* with *Gain frame* as the reference case). Figure D1 reflects the distribution of the predicted values of r of the EUT model (with covariates). The results indicate the presence of both risk-loving and risk-averse behaviour within the sample.

With respect to flood adaptation, table E1 suggests that individuals that use plastic sheeting and that opt to raise their home above ground are less risk averse relative to individuals that slant their roofs, however, these results are only significant at the 10% level: Specifically, for those individuals relying solely on plastic sheeting, RRA decreases by 0.540 ($p = 0.058$, CI: -1.098, 0.018). Furthermore, individuals who raise their home above ground are less risk averse relative to those that slant their roofs ($p = 0.099$, CI: -0.719, 0.061).

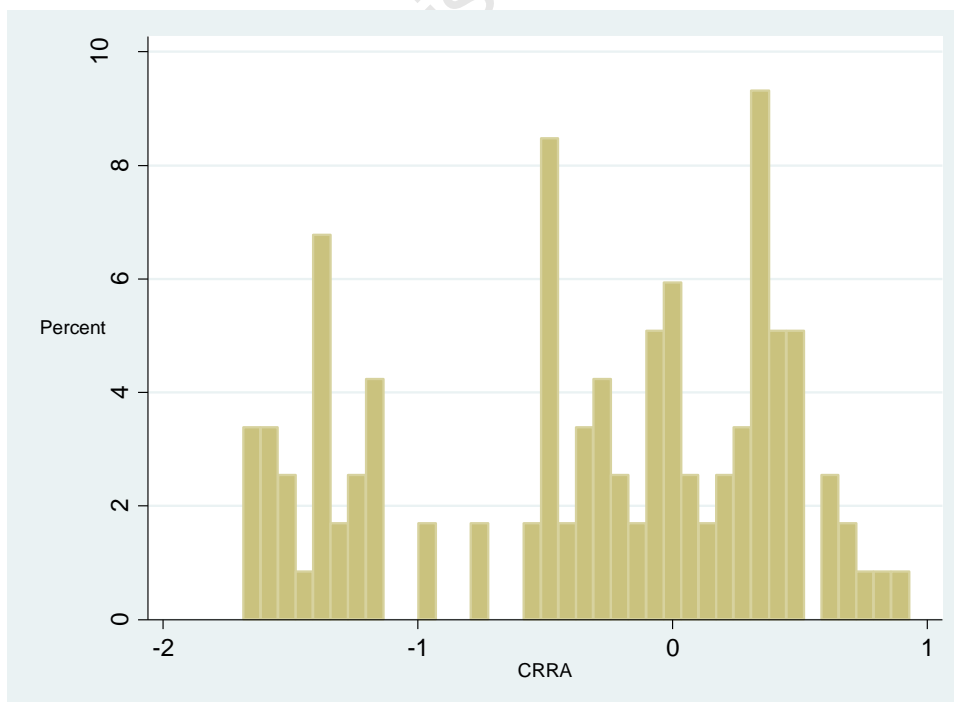
Table E1. EUT model

		Coef.	Robust Std. Err.	95% Conf. Interval	
Panel A					
r	Cons	-0.0698	0.0906	-0.2474	0.1077
mu	Cons	0.1634**	0.0151	0.1339	0.1930
Panel B					
r	Cons	1.068**	0.388	0.308	1.829
	Loss frame	-1.977	1.885	-5.672	1.718
	Mixed frame	-0.724	0.426	-1.559	0.110
	Female	-0.011	0.172	-0.349	0.327
	Grade-12	-0.081	0.280	-0.629	0.468
	Age \geq 40	0.009	0.183	-0.351	0.368
	HH income \leq 2000	-0.094	0.211	-0.508	0.320
	Unemployed HH	-0.044	0.204	-0.444	0.356
	Do nothing	-0.545	0.422	-1.372	0.282
	Plastic sheeting	-0.540	0.285	-1.098	0.018
	Home above ground	-0.329	0.199	-0.719	0.061
	Flooding	-0.177	0.283	-0.731	0.378
mu	Cons	0.172	0.062	0.052	0.293

Notes:

- * and ** signify significance at the 5% and 1% level, respectively
- Standard errors adjusted for clustering

Figure E1. Constant Relative Risk Aversion



Risk Preferences, Technology Adoption and Insurance Uptake: a Framed Experiment

Kerri Brick

Abstract

Despite the yield improvements associated with the adoption of new farming technologies and modern inputs, technology diffusion amongst small-scale farmers in developing countries is slow. In this context, given the inherently risky environments in which farmers in the developing world operate, poor households are thought to be caught in a risk-induced poverty trap; specifically, poorer households that are unable to insulate themselves from consumption risk avoid these risks by opting for lower return, lower risk agriculture, and thus do not benefit from technological innovation. Using a series of laboratory experiments in a South African setting, this paper examines whether the provision of a framed index insurance product induces individuals to opt into riskier but potentially more profitable activities. To do so, we use a simple gambling task with real monetary prizes to elicit subjects' risk preferences. Elicited risk preferences are applied to the uptake of credit and insurance in a series of framed insurance simulation games. Experiment participants are small-scale and subsistence urban food growers. Overall, the results of the experiment lend empirical weight to the poverty-trap argument. Firstly, a high degree of risk aversion is evident among the sample. Secondly, risk-averse individuals are more likely to opt into traditional agriculture (reflected as traditional seeds in the experiment) and are less likely to use modern farming inputs that require financing (high-yield varieties) despite the availability of insurance. The results indicate that the provision of index insurance is not a panacea for the problem of promoting technology diffusion to small-scale farmers in the developing world, but that residual production risk and basis risk must be considered in the contract design.

Key words: technology adoption, farmers, index insurance, risk preferences

1 Introduction

Despite the potential for yield improvements from the adoption of new farming technologies (such as high yield varieties) and modern inputs (such as fertiliser), the rate of adoption among small-scale and subsistence farmers in developing countries is slow (Feder *et al.* 1985, Cornejo *et al.* 2002, Simtowe 2006, Engle-Warnick *et al.* 2007, Duflo *et al.* 2011). While risk aversion and imperfect credit and insurance markets are widely credited as key factors in the slow rate of technology diffusion (Humphrey and Verschoor 2004, Giné *et al.* 2008, Giné and Yang 2009), it is difficult to distinguish the impact of constrained credit, on the one hand, from appetite for risk, on the other. Specifically, while wealthier households have greater access to the credit necessary to finance agricultural investment, they are also better equipped to bear the higher risk burden associated with investment in new agricultural technologies (Giné and Yang 2009). Recognizing the role of risk attitudes as a barrier to technology adoption that is independent of wealth effects implies that promoting technology diffusion requires more than simply providing access to credit. For example, even when credit is available for the financing of agricultural investment, borrowers risk defaulting on their loans in the event of crop failure – a risk that is greater for borrowers who are uninsured. In this context, the provision of bundled credit and insurance products are better suited to facilitating technology adoption relative to the provision of credit alone.

Against this background, this paper contributes to the existing literature by, firstly, disentangling the role of risk aversion on investment choices from wealth effects and credit constraints and, secondly, testing whether low investment rates can be overcome by offering bundled credit and insurance products. To do so, we first use a framed game coupled with simple risk experiments to identify which participants choose low-risk, low-yield strategies. In terms of the framing of the game, participants, who consist of a sample of South African subsistence farmers, are choosing between traditional agriculture versus investing in a new farming input which requires them to take out a loan. Next, we test whether the provision of a framed insurance product (bundled with a loan) induces those individuals who chose the low-risk strategies in the first part of the experiment to opt into more risky but potentially more profitable activities in the second part. To our knowledge, this is the first paper to explicitly test the effect of insurance on technology adoption among subjects who have already demonstrated risk aversion. More specifically, while a number of other studies use insurance

simulation games to reveal farmers' preferences around insurance (the reader is referred to Carter *et al.* 2008, Patt *et al.* 2009 and Patt *et al.* 2010), these studies do not untangle the effects of risk preferences from credit constraints by considering farmers' choices first *without* and then *with* the possibility of insurance.

By considering risk aversion as a barrier to technology adoption and further assessing the role of insurance in overcoming this barrier, we are able to provide interesting insights into the risk-induced poverty-trap hypothesis – whereby risk-averse farmers opt into low-return and low-risk agricultural strategies – and the possible role of insurance in breaking this cycle (Mosley and Verschoor 2005). In this context, three recent studies indicate that the provision of insurance does actually promote agricultural investment into higher-yielding but higher-risk strategies.⁵² Cole *et al.* (2013b) conduct a randomised field experiment with small agricultural firms in India (with many firms consisting of one family) where the treatment group is provided with a number of rainfall insurance policies while the control group is provided with a fixed cash payment. The authors find that provision of insurance significantly increases production of cash crops (crops with higher expected returns relative to other types but that are more sensitive to rainfall variability). Mobarak and Rosenzweig (2012), who conduct a randomised experiment with farmers in India, find that insured farmers are more likely to plant riskier but high-yielding crops. In a randomised trial set in Ghana, Karlan *et al.* (2012) offer small-scale farmers cash grants, rainfall insurance grants or both. The authors find that, while rainfall insurance results in both greater investments in agriculture and riskier production choices, the effect of the cash grant is relatively small. The authors conclude that uninsured risk poses a binding constraint to agricultural investment.

Overall, the results of the experiment lend empirical weight to the poverty-trap argument. Firstly, a high degree of risk aversion is evident among the sample. Secondly, risk-averse individuals are more likely to opt into low risk, low return agricultural strategies and are less likely to use modern farming inputs that require financing – despite the availability of insurance.

⁵² These randomised control trials consider the impact of insurance on farmers' behaviour. As such, the treatment group is provided with insurance while the control group is not.

The insurance product in this experiment is designed to reduce the loss experienced by the participants in the event of a negative event (framed in the games as crop failure from poor rainfall), but does not remove this loss entirely. This design element reflects the idea that index insurance does not remove all risk from the production process. For example, index insurance introduces basis risk – whereby a farmer experiences a loss but does not receive an insurance payout (Patt *et al.* 2009). In this context, like Karlan *et al.* (2012), we find uninsured risk to act as a barrier to agricultural investment. The results indicate that the provision of index insurance is not a panacea for the problem of promoting technology diffusion to small-scale farmers in the developing world, but that residual production risk and basis risk must be considered in the contract design.

The remainder of this paper is as follows: a literature review is provided in Section 2, while a simple theoretical model is provided in Section 3. The sample statistics are discussed in Section 4 while the experimental design and procedures are outlined in Section 5. The results are discussed in Section 6 and the paper concludes with a discussion in Section 7.

2 Literature review

The reviewed papers are structured so as to consider insights about: (1) credit constraints/wealth and insurance uptake, (2) risk aversion and insurance uptake, (3) wealth/access to credit and investment behaviour, (4) risk aversion and investment behaviour and (5) the correlation between credit/wealth and risk aversion and the risk-induced poverty trap.

Studies indicate that credit constraints and low levels of wealth diminish insurance uptake. Cole *et al.* (2013a) report that liquidity constraints reduce demand for a rainfall insurance product in India. The authors argue that, as households must buy insurance at the start of the farming season, when other farming inputs such as seeds, labour and fertiliser also need to be purchased, only wealthier households are able to afford insurance. Giné *et al.* (2008) examine the uptake of a rainfall insurance product amongst small scale farmers in India. Their results confirm that wealthy households are more likely to take up the insurance product, while uptake is lower among households that are credit constrained.

In terms of the relationship between risk aversion and insurance uptake, Giné *et al.* (2008) also find risk averse households to be less likely to purchase insurance if they are unfamiliar with insurance in general, or with the microfinance organisation offering it. These results indicate that, in addition to access to credit, risk attitudes act as further constraints to the uptake of insurance.

Now considering the relationship between wealth or access to credit and investment in new technology. Investment behaviour is constrained in environments where farmers lack access to the credit facilities necessary to finance inputs (e.g., fertiliser). A number of studies show adoption to be correlated with wealth. Croppenstedt *et al.* (2003) find limitations around access to credit to be a significant supply-side constraint to the adoption of fertiliser by Ethiopian farmers. The authors argue that the cash resources available to households are insufficient to finance fertiliser purchases. Chirwa (2005) finds that the adoption of fertiliser among farmers in Malawi increases with income and plot size (an indicator of wealth). Dercon and Christiaensen (2011) examine the link between consumption risk and fertiliser adoption amongst small-scale farmers in Ethiopia. The authors note that, while average yields (and returns) are higher with fertiliser, given the sunk cost associated with using fertiliser, overall yields are lower than they would have been without fertiliser when harvests are low (for example, because of lack of rain). This makes adoption of fertiliser fairly risky. The results indicate that downside consumption risk (from low rainfall and a consequently poor harvest) discourages fertiliser usage. However, households with more livestock (a measure of liquidity) and male-headed households (also a proxy for wealth) are more likely to adopt fertiliser. Note that the authors used a fixed effects logit model, thus ensuring that all time-invariant household characteristics – most notably risk preferences – are captured.

Farmers in the developing world, who operate in extraordinarily risky environments, are faced with a number of production risks – given their reliance on rain fed agriculture, the most notable of these is climate variability (Hazell *et al.* 2010). As such, in situations where credit *is* accessible but where insurance markets are imperfect (and thus access to insurance is limited or non-existent), potential borrowers are deterred from taking loans amid the high costs associated with loan default (for example, in the event of crop failure), such as confiscation of assets (Giné and Yang 2009). More broadly, as production failure is one of the primary sources of income variability among small-scale and subsistence farmers, and because modern farming inputs are more profitable but also more risky, households attempting to insulate themselves

from fluctuations in income might decide not to adopt new farming practices and inputs (Dercon and Christiaensen 2011). Against this background, Liu (2008) relates Chinese farmers' risk attitudes to the adoption of a new production technology (Bt cotton). The author finds that farmers who are more risk and loss averse adopt new technologies later. Using survey data from Malawi, Simtowe (2006) finds that the adoption of hybrid maize is lower for farmers who exhibit risk aversion around the use of fertiliser (a complementary input for maize).

Giné and Yang (2009) point out the likely correlation between access to credit, on the one hand, and willingness to take on risk (for example, by investing in a new input) on the other. Wealthy households will have greater access to credit relative to less wealthy households. Furthermore, wealthier households are more likely to invest in new inputs because they can better bear the associated risk burden. It is thus unclear whether it is constrained credit or rather limited access to insurance markets (to address production risk) that is the main driver of the slow pace of technology diffusion (Giné and Yang 2009). Two papers that go some way toward untangling the effect of credit constraints versus appetite for risk are those of Giné and Yang (2009) and Giné *et al.* (2008). Giné and Yang (2009) run a randomised field experiment in Malawi to assess whether provision of insurance facilitates the uptake of loans (to finance a new crop technology). Half the farmers in the sample were offered a loan without insurance, while the remaining farmers were offered loans bundled with rainfall insurance. While take-up of the basic loan (without insurance) was 33%, take-up of the loan bundled with insurance was lower – at 17.6%. The authors suggest that the limited liability clause in the loan contract acted as *de facto* insurance. Additionally, take-up of the insured loan was correlated with income, wealth and education. Using household survey data, Giné *et al.* (2008) examine the determinants of Indian farmers' insurance participation. Their results indicate that both access to credit and risk attitudes act as constraints to uptake.

This link between risk attitudes and investment behaviour perpetuates a risk-induced poverty trap. Mosley and Verschoor (2005) note that risk aversion is a key element in the poverty trap: poor individuals who are risk averse – and thus unwilling to invest in modern inputs because of the associated production/consumption risks – will remain poor, while wealthier individuals who are in a position to insulate themselves from risk will benefit from technological innovations and become wealthier still. Similarly, Giné and Yang (2009) argue that risk-averse farmers might opt for lower-yielding, traditional farming technologies that don't require

financing. Insurance products that reduce the consumption risks associated with the use of modern inputs would thus promote technology diffusion and help break the poverty-trap cycle.

3 A model of risk preferences and insurance

Using a simple model adapted from Humphrey and Verschoor (2004), who illustrate the role of risk preferences in the uptake of micro-credit schemes, we consider the rationale behind index insurance in the context of risk preferences.

The assumptions used in this model echo the framing of the insurance simulation games that will be discussed in a subsequent section. Specifically, we assume that, in order to finance new farming technologies (for example high-yielding seeds or fertiliser), farmers need to take out a loan. The loan needs to be repaid at the end of the farming period, irrespective of whether the farmer experiences production failure. By bundling the loan with weather index insurance, the farmer is able to reduce the costs associated with production failure.

Ignoring insurance at first, we assume a farmer can plant either traditional seeds or high-yielding seeds. The returns from traditional seeds are fairly certain and these seeds do not require financing. As such, the farmer earns a return on traditional seeds of $2y$.

The returns from the improved seeds are dependent on the level of rainfall (in other words, there is an element of production risk), where the probability of good rain is 0.5. With good rain, the farmer earns a return of $4y$; however, when the rains are low, the farmer earns a return of 0, net of loan repayment.

A risk averse individual would choose to plant traditional seeds because $u(2y) > 0.5u(4y) + 0.5u(0)$. Conversely, a risk neutral individual would be indifferent between the two options because $u(2y) = 0.5u(4y) + 0.5u(0)$.

Insurance would work to encourage the uptake of high-yielding seeds through mitigating losses when the rains are low. In this case, when rainfall is low, instead of earning 0, the farmer earns $1.5y$ (still less than if s/he had opted for traditional seeds). However, the farmer needs to pay for the insurance irrespective of the level of rainfall, but, as in the case of index insurance, does not receive a payment when the rains are good. In the event that the farmer purchased insurance

and the rainfall is good, the farmer earns $3y$ (as opposed to $4y$). The utility from purchasing the insurance product is thus $0.5u(3y) + 0.5u(1.5y)$.

The risk neutral farmer will now select the insurance option as opposed to the traditional seed option because $0.5u(3y) + 0.5u(1.5y) > u(2y)$. In addition, the risk averse farmer at the margin may also opt for the insurance option because $0.5u(1.5y) > 0.5u(0y)$.

4 Sample

The sample consists of 82 small-scale and subsistence farmers who grow organic produce in vegetable gardens situated in urban informal settlements around Cape Town, South Africa. Produce is rain-fed, rendering the farmers extremely susceptible to variations in rainfall.

Sample statistics are provided in table 1. On average, participants are 54 years old and approximately 62% are female. Levels of education are low throughout the sample. In terms of highest level of education completed, around 13% of the sample have no schooling or obtained some pre-primary school education. Approximately 24% have some primary school education while just over 12% completed their primary schooling (Grade 7). Just under 33% have obtained some high school education (Grades 8-11) and around 7% have obtained a Grade 12 qualification.

Monthly household income is extremely low – with around 98% of households earning less than \$271⁵³ per month. Moreover, for nearly half the sample, monthly household income is less than \$90 per month.

Around 79% of participants indicated that they had never applied for a loan from a bank or other financial institution. The main reasons given by participants for not applying for a loan include: the perception that a loan is too expensive and difficult to repay (37%), the perception that the loan would not be granted (24%), preference for borrowing money from family and friends (21%), preference to not borrow money from anyone (15%) and uncertainty with respect to how to go about applying for a loan (5%).⁵⁴

⁵³ \$/Rand = 11.06 on 10 February 2014.

⁵⁴ Note that participants could select multiple options.

Table 1. Sample statistics

	All	Session 1	Session 2	Session 3
	<i>n</i> = 82	<i>n</i> = 29	<i>n</i> = 29	<i>n</i> = 24
Age				
Mean	53.85	57.86	57.14	45.17
Std. Dev.	14.36	11.48	12.69	16.00
Median	56.00	62.00	58.50	49.50
Female (%)	0.62	0.64	0.61	0.61
Education (%)				
No schooling	0.13	0.14	0.21	0.04
Incomplete primary schooling	0.24	0.28	0.31	0.13
Complete primary schooling	0.12	0.21	0.10	0.04
Some secondary schooling	0.33	0.24	0.28	0.50
Grade 12	0.07	0.00	0.03	0.21
Household size				
Mean	5.23	5.10	5.41	5.17
Std. dev.	1.85	1.74	2.23	1.49
Median	5.00	5.00	5.00	5.00
HH income (%)¹				
\$0 – \$23	0.15	0.10	0.04	0.41
\$23 – \$45	0.11	0.19	0.04	0.12
\$45 – \$90	0.20	0.24	0.30	0.00
\$91 – \$181	0.42	0.33	0.56	0.29
\$181 – \$271	0.11	0.10	0.07	0.18

Notes: ¹ 65 respondents answered this question; 21 in session 1, 27 in session 2 and 17 in session 3; percentages are calculated from these totals.

As expected, uptake of credit is low in the sample. Around 15% of participants have a store card with a South African retailer, 5% of participants have a bank loan, and only 1% of participants have a credit card. Conversely, 18% of participants indicate having an existing loan from a friend or family member.

In the survey, participants were asked how they finance new farming inputs and equipment. The proportion that obtains finance through a bank is extremely low at 1%. Around 38% use personal savings, 16% borrow money from an informal savings group, 12% borrow money from family and friends, and 24% utilise other resources (such as obtaining money from local NGOs and municipalities).

As anticipated, given the low levels of income prevalent in the sample, the uptake of formal insurance (with the exception of funeral insurance) is extremely low. While 29% of participants have a funeral policy, only 2% have some form of life insurance and 1% have medical insurance.

5 Experimental design

The experiment is a within subject design whereby each subject participated in all games. In terms of the setup, subjects first completed a series of risk games (with probability levels of 30%, 50% and 70%) before participating in two series of insurance games:

In the first series of insurance games, participants chose between: (i) traditional agriculture, framed as traditional seeds (TS) not requiring financing and, (ii) modern farming inputs, framed as high-yielding seeds that are financed through a basic loan (HYL). Subjects played three games, each with a different probability of production risk (namely, 30%, 50% and 70%). Note that as each game is a new game, income does not accumulate and is not carried over from one game to the next. As participants chose between traditional seeds and high-yielding seeds with a loan, we refer to this series of insurance games as *series 1* or *TS vs. HYL*.

In the second series of insurance games, in addition to TS and HYL, participants could select a third option of high-yielding seeds – but this time the basic loan is bundled with rainfall insurance (HYI). Again, there are three games with varied probability levels of 30%, 50% and 70%. We refer to this set of insurance games as *series 2* or *TS vs. HYL vs. HYI*.

Lastly, once all the games were concluded, participants filled out a survey.

The risk and insurance games as well as the experimental procedures are discussed in more detail in the following subsections.

5.1 Risk games

Subjects are presented with three gambles and, in each gamble, make a series of choices between (i) an increasing sure payoff and (ii) a risky prospect. As is evident from table 2, the probability levels of the three games are 30%, 50% and 70%, respectively.

Table 2. 30%, 50% and 70% gambles (in Rand)

Game	Option 1			Option 2	
	Minimum	Maximum	Probability	Prize	EV
1	R3	R26	30%	R50	R15
2	R13	R36	50%	R50	R25
3	R23	R46	70%	R50	R35

Appendix A illustrates the decision sheet for game 1 (30% gamble). In each row, subjects choose between an increasing sure payoff (Option 1) and a risky prospect (Option 2). Following Moore and Eckel (2006), the increasing sure payoff offered under Option 1 ranges between R3 and R26 and increases in R1 increments; this incremental increase is common across all the decision sheets. The mechanism of specifying a range for the sure payoff prevents participants from specifying unreasonable certainty equivalents – for example, a certainty equivalent of more than R50 for a gamble with a maximum prize of R50 (Moore and Eckel 2006). With respect to Option 2, the payoff remains constant throughout the decision rows, with players either earning R50 or nothing, with an expected value of R15. An extremely risk averse individual would prefer Option 1 in the first row of the decision sheet, while an extremely risk-seeking subject would prefer Option 2 in the last decision row. The point at which a participant moves over from Option 2 to Option 1 provides a measure of the subject's certainty equivalent.

The presence of multiple switching points (when subjects switch back and forth between Option 1 and Option 2 when moving down the rows of the decision sheet) is common in experiments which elicit a switching point (Holt and Laury 2002) and particularly when such experiments are carried out in developing countries (Galarza 2009, Jacobson and Petrie 2009, Brick and Visser 2011). Against this background, the instructions were carefully worded to make the logical inconsistency of multiple switching apparent to the participants (an excerpt of the instructions is provided in Appendix B).

Using a Multiple Price List (MPL) format similar to the one used in this experiment, Tanaka *et al.* (2010) enforced monotonic switching by explicitly asking subjects to state at which row they wanted to switch from one option to another. Participants went through the instructions and played a practice round, and were then asked to specify the row in which they wanted to switch from Option 2 to Option 1.

Note that various examples were provided to participants in this experiment on the day, including: only selecting Option 1, only selecting Option 2 and switching from Option 2 to Option 1 at various rows. In this way, participants did not feel forced to switch at a particular point.

While 84 subjects participated in the experiment, two of the subjects exhibited multiple switching behaviour and have been excluded from the sample – leaving a sample of 82 farmers.

5.2 Insurance games

5.2.1 Series 1: TS vs. HYL

In each of the three games, participants choose between two types of seeds: traditional seeds or high-yielding seeds. The payoff from each seed type is determined by the level of rainfall – which can be high (good) or low.

In terms of the framing, the farmers are told to consider traditional seeds as those seeds with which they are familiar. As these seeds are saved every year, they do not cost anything. While the payoff from this seed type is less variable, it is lower relative to other seed types. As appears from table 3, the payoff from traditional seeds is R10 if rainfall is good, and nothing when the rains are low.

Once again, as per the framing, farmers are told to think about high-yielding seeds as a new seed type that can increase their harvest when the rains are good but that perform badly when the rains are low. Improved seeds need to be purchased annually. Because of this cost, in order to purchase improved seeds, participants need to take out a loan of R35 at the bank. This loan is repaid at the end of each round. The payoff from improved-seeds, when the rains are good,

after paying back the loan, is R100. When the rains are bad, instead of earning nothing as in the case with traditional seeds, participants lose R35 after repaying the loan.

Table 3. Framed experiments, payoffs

<i>Series 1</i>		
	Rainfall	
	Good	Low
TS	10	0
HYL	100	-35

<i>Series 2</i>		
	Rainfall	
	Good	Low
TS	10	0
HYL	100	-35
HYI	80	-10

Notes:

- TS: Traditional seeds
- HYL: High-yielding seeds (with loan)
- HYI: High-yielding seeds (with loan bundled with insurance)
- The probability of good rain changes in each round:
 - 30% in round 1
 - 50% in round 2
 - 70% in round 3

As previously mentioned, subjects participate in three games. In each game, the probability of “good” rain is varied. Following the percentages in the risk experiments outlined previously, the probability of good rain varied over the games as follows: game 1 (30%), game 2 (50%) and game 3 (70%).

5.2.2 Series 2: TS vs. HYL vs. HYI

In the second series of insurance games, farmers are now able to choose between traditional seeds, high-yielding seeds with a loan, and a third option of high-yielding seeds with a loan and a rainfall index insurance product.

It is explained to participants that they can buy rainfall insurance for R20 as a means to protect their income and reduce their losses when the rains are low. It is emphasised that, if the rains are good, there is no return from the insurance. In this case, the payoff from high-yielding seeds coupled with the loan and insurance, after paying back the loan and paying for insurance, is

R80 (table 2). However, if the rains are low, participants receive R45 back from the insurance company, reducing the loss to R10 (table 3).

The expected values (EV) and standard deviations (SD) associated with each choice are reflected in table 4 (not provided to participants). As is apparent from the table, for all probability levels, the traditional seed option has the lowest EV and SD. In addition, again for all probability levels, the high-yielding loan option has the highest SD (and this hierarchy is intact across all probability levels).

Table 4. Expected values and standard deviation

Prob. of good rain:	30%		50%		70%	
	EV	SD	EV	SD	EV	SD
TS	2.99	4.56	4.98	4.98	6.97	4.56
HYL	5.50	61.86	32.50	67.50	59.50	61.86
HYI	17.00	41.24	35.00	45.00	53.00	41.24

Notes:

- TS: Traditional seeds
- HYL: High-yielding seeds (with loan)
- HYI: High-yielding seeds (with loan bundled with insurance)

When the probability of good rainfall is low (30%), the EV of the option of high-yielding seeds bundled with a loan and insurance (HYI) exceeds the EV of the choice of high-yielding seeds with loan (HYL). Conversely, as expected, when the probability of good rain is high (70%), the EV of the loan option exceeds the EV of the insured-loan option.

5.3 Experiment procedures

The experiments were repeated over three days – with a total of 84 farmers participating. As mentioned previously, two of the subjects who exhibited multiple switching behaviour have been excluded from the sample, leaving a sample of 82. The same enumerator went through the instructions on each day and the same translator was present to translate the instructions into Xhosa.

At the start of the day, participants were told that they will earn R180 for participating in the experiment and for filling in a survey. In order to eliminate as far as possible any house money effects, it was emphasised that, while this R180 was theirs to take home, any money earned or

lost throughout the day would be added or deducted from the R180 already earned. Subjects were paid at the end of the day by cash cheque.

Note that games other than those discussed here were conducted on the day – but as these are not analysed in this article, they are not mentioned here.

Large poster-sized versions of the decision sheets were used to illustrate the examples, and participants first played a practice round for most of the games.

Given the low levels of education and numeracy prevalent in the sample, the probabilities associated with both the risk and insurance games were conveyed to participants with the use of spinning wheels. The enumerator referred to the relevant spinning wheel when explaining a particular game and the spinning wheel was displayed while participants were making their decisions.

In terms of the payment mechanics, the probabilities were also operationalised with the use of the spinning wheels. For the risk games, once the decision sheets for a particular game were collected, a participant would draw a ball from a bag to determine which row in the decision sheet was to be played for money. The spinning wheel was then spun so that participants who had selected risky Option 2 could determine their earnings from the game. Similarly, in the insurance games, once a particular game was concluded, the spinning wheel was spun to determine whether the level of rainfall was good/low (and so that participants could determine their earnings based on the choices they made). While this procedure was followed after each game (risk and insurance), participants were told upfront that they would not be paid for all games but would rather receive payment for one of the three risk games, one of the three insurance games in series 1 (TS vs. HYL) and, similarly, one of the three insurance games in series 2 (TS vs. HYL vs. HYI). As the random draw determining for which games participants would be paid was conducted at the end of the day, while participants were able to keep track of their potential earnings from each game, they only learnt their actual earnings at the end of the day. This design element, combined with the fact that each (risk and insurance) game represented a new game – thus ensuring that income did not accumulate throughout the games, mitigated the potential for accumulated income to affect participants' behaviour in the games.

There was no asymmetry of information between the experimenter and the participants. Neither the experimenter nor the participants knew *a priori* which row would be played for money and what the outcome of the spinning wheel would be.

Finally, participants earned on average \$21 during the workshop.

6 Results

This section proceeds as follows: in Section 6.1, participants risk attitudes are described. Section 6.2 examines: (i) the relationship between risk aversion and technology adoption and, in particular, whether risk aversion explains low investment rates in new farming strategies and, (ii), whether the provision of insurance induces individuals who had previously chosen low-risk strategies to opt into higher-risk but potentially higher-return farming strategies.

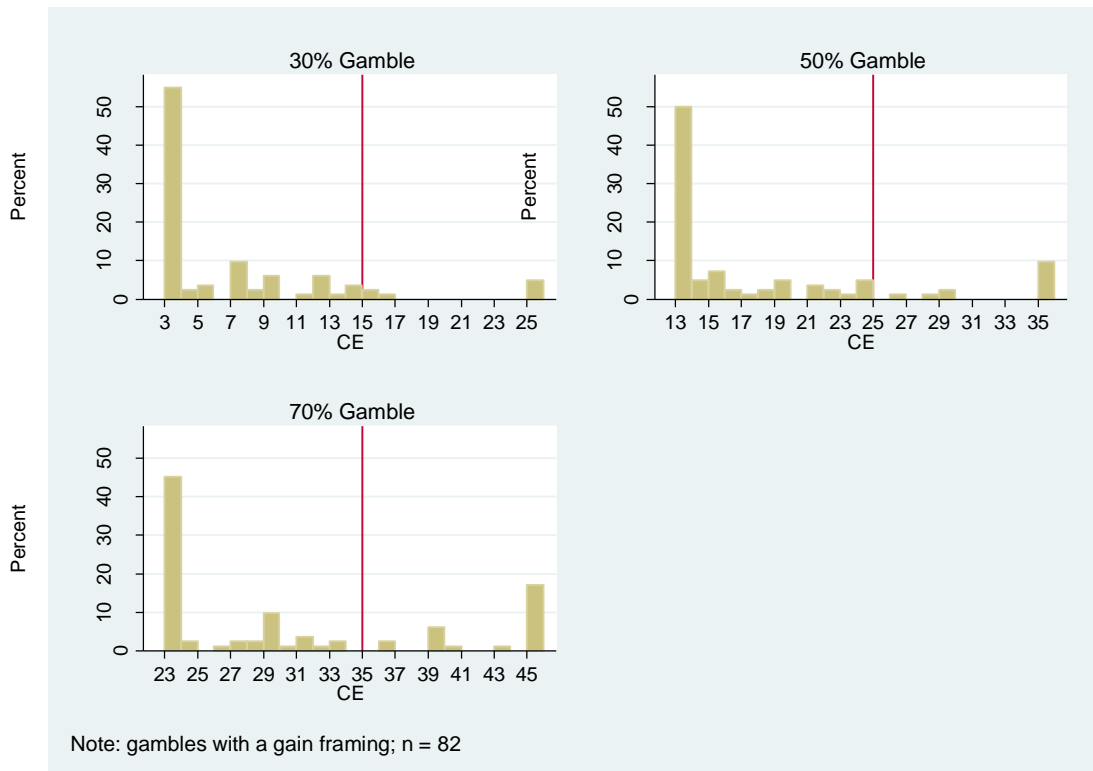
As previously mentioned, two of the subjects exhibited multiple switching points and were removed from the sample – leaving a sample of 82 subjects.

6.1 Risk attitudes

Figure 1 reflects the distribution of certainty equivalents amongst the different risk games. As is evident from the figure, the choices made by the participants reflect a significant degree of risk aversion. As evident from figure 1, a significant proportion of participants in each risk game always selected the safe Option 1 – and so revealed the lowest possible certainty equivalent. These proportions are as follows: 30% game: 51% of participants; 50% game: 49% of participants; 70% game: 45% of participants. Additionally, again in each game, the majority of subjects revealed certainty equivalents below the expected value of the gamble: 30% game: 92% of participants; 50% game: 85%; 70% game: 72%.

Akay *et al.* (2011) conducted comparable risk experiments with 92 Ethiopian farmers. Using a probability gamble of 50%, the authors found a similarly high level of risk aversion with nearly 45% of their sample (41 farmers) revealing the lowest possible certainty equivalent.

Figure 1. Frequency distributions of certainty equivalents



Note: Expected value of gamble reflected by red line

Because participants filled out a survey capturing their demographic information, we are able to regress the risk attitudes on a set of explanatory variables. Note that we avoid dependence on assumptions around the theory of utility maximisation by using the certainty equivalents directly to create a measure of risk aversion.⁵⁵ In addition to the certainty equivalents being censored at lower and upper bounds (table 2), as mentioned above, around half the participants in each gamble selected the lowest possible certainty equivalent. Therefore, we use a panel data tobit model. In order to estimate the regression, we convert participants' certainty equivalents for each gamble into a number between 0 and 1 as follows: $(CE - CE_{UL}) / (CE_{LL} - CE_{UL})$, where CE is the participants' certainty equivalent, CE_{UL} is the upper limit and CE_{LL} is the lower limit. Using this measure, the certainty equivalent is converted into a value between 0 and 1 with a value of zero signifying risk-seeking behaviour, a value of 0.5 indicating risk neutrality and a value of 1 indicating risk aversion.

⁵⁵ For comparison with other studies, table C1 in Appendix C provides the bounds on r implied by subjects' choices when a Constant Relative Risk Averse (CRRA) utility function (defined over the lottery prize) is assumed (Holt and Laury 2002, Andersen *et al.* 2008, Andersen *et al.* 2010, Harrison and Rutström 2008).

Explanatory variables incorporated into the model include dummy variables for session, probability level of gamble (with the 70% gamble being the reference case), gender, whether a participant is 50 years or older, whether a participant has finished high school, and, finally, whether a participant earns an income greater than R500. The dependent variable is the participants' CE ratio. Positive coefficients indicate increasing risk aversion. The regression results are reflected in table 5.

Table 5. Regression analysis of the determinants of risk aversion

VARIABLES	COEFFICIENT
Session1	0.158 (0.194)
Session2	0.113 (0.224)
30% Gamble	0.295** (0.106)
50% Gamble	0.185 (0.095)
Female	0.010 (0.164)
Age > 50	0.244 (0.183)
High School	0.157 (0.202)
Income > R500	-0.006 (0.161)
Constant	0.518 (0.244)*

Notes:

- ** $p < 0.01$, * $p < 0.05$
- Panel tobit regression
- Dependent variable: *CE ratio*
- Positive coefficients indicate increasing risk aversion

The results indicate that subjects are significantly more risk averse in the 30% and 50% gambles relative to the 70% gamble; however, this result is only significant at the 10% level for the 50% gamble (30% gamble: $p = 0.002$; 50% gamble: $p = 0.082$).

6.2 Risk aversion, insurance and technology adoption

Table 6 reflects the uptake (as a percent) of each of the framed seed options in both series 1 and series 2. This information is represented graphically in parts 1 & 2 of figure 2. To recap, in series 1, the farmers choose between traditional seeds (TS) and high-yielding seeds with a

loan (HYL), while in series 2, farmers are additionally able to opt for high-yielding seeds with a loan and insurance (HYI).

Starting with series 1, in the first game, when the probability of good rainfall is 30%, more than half of the participants (54%) select the traditional seed option, while 46% opt for the uninsured loan. As the probability of good rainfall increases, the proportion favouring the traditional seed option declines: for example, in the 70% game, 27% of participants opt for traditional seeds as compared to 73% opting for the high-yielding seeds (with loan). This is illustrated graphically in part 1 of figure 2.

In series 2, when the probability of good rainfall is 30%, the majority of participants (46%) opt into the high-yielding seeds (with loan and insurance), while 33% and 21% respectively choose traditional seeds and high-yielding seeds (loan). Demand for insurance remains relatively unchanged throughout the games, despite the increasing probability of good weather. Conversely, the demand for traditional seeds declines to 18% in the 70% game while the uptake of the high-yielding seeds with loan increases to 35%. This is illustrated graphically in part 2 of figure 2.

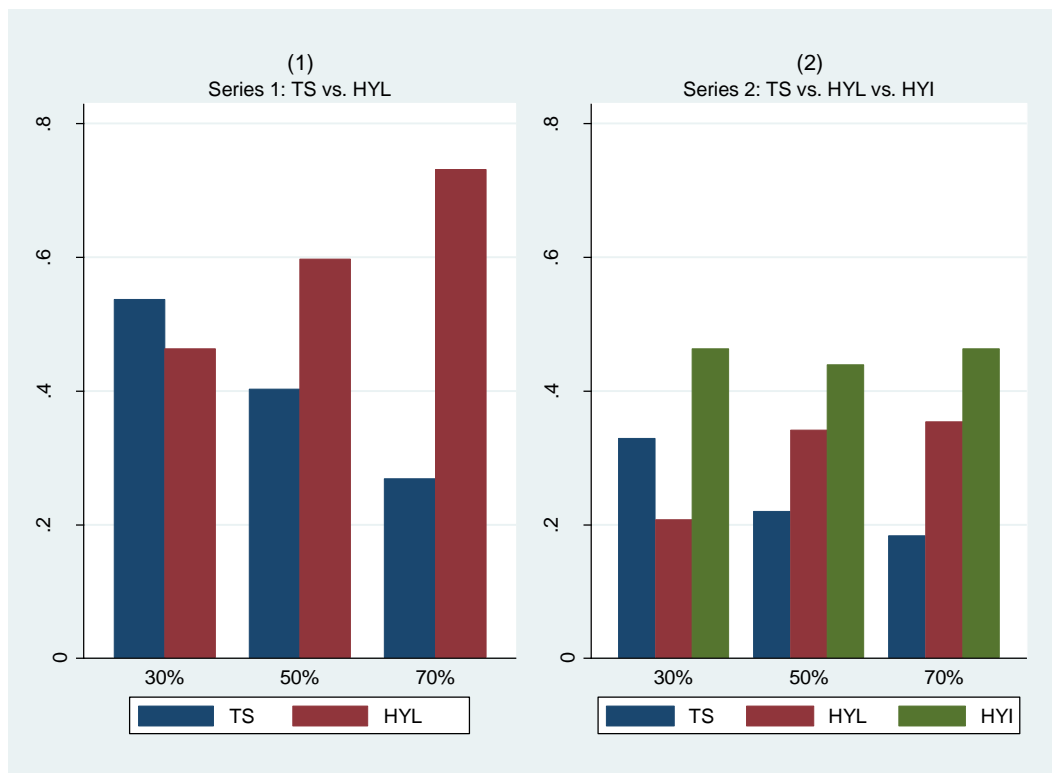
Table 6. Uptake of each option in the simulated insurance games

Prob. of good rain	Treatment 1		Treatment 2		
	TS (%)	HYL (%)	TS (%)	HYL (%)	HYI (%)
30%	54	46	33	21	46
50%	40	60	22	34	44
70%	27	73	18	35	46

Notes:

- TS: Traditional seeds
- HYL: High-yielding seeds with loan
- HYI: High-yielding seeds with loan and insurance

Figure 2. Uptake of framed seed options in the simulated insurance games

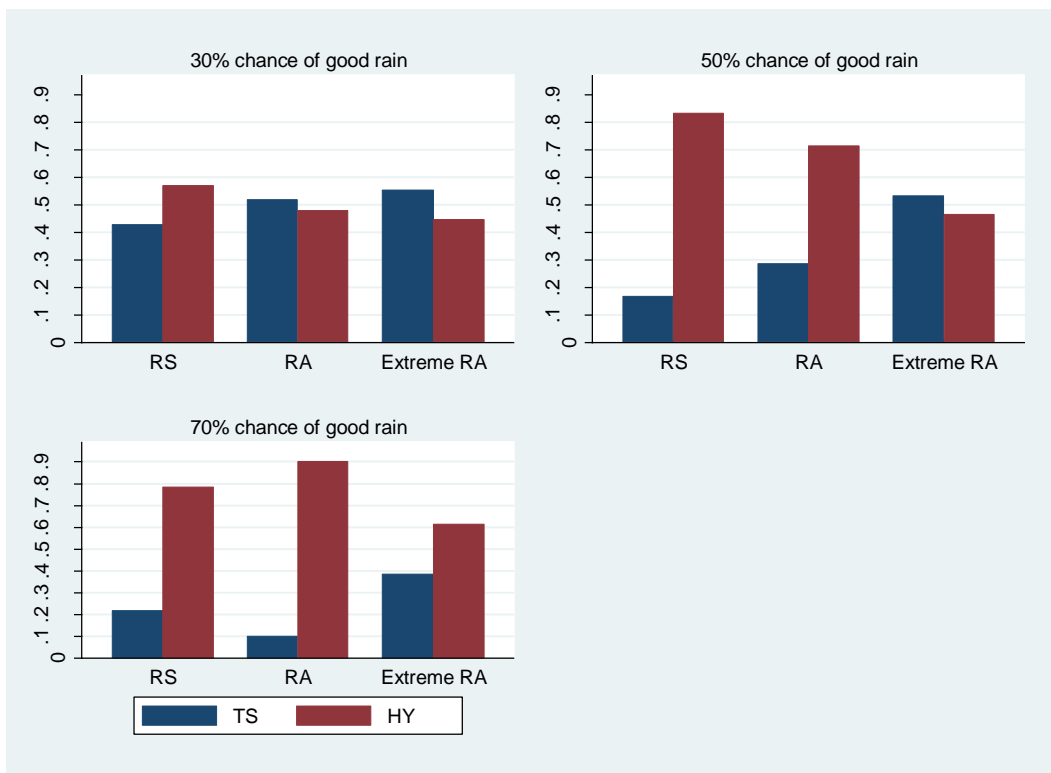


Notes:

- TS: Traditional seeds
- HYL: High-yielding seeds with loan
- HYI: High-yielding seeds with loan and insurance

Using the CE ratio described earlier, we devise three categories of risk preferences: namely risk seeking (CE ratio < 0.5), risk averse ($0.5 < \text{CE ratio} < 0.9$) and extremely risk averse (CE ratio ≥ 0.9). Figure 3 reflects the uptake of each option in series 1 of the insurance games (TS vs. HYL) by risk category. In general, uptake of the traditional seed appears to be increasing in risk aversion while, conversely, uptake of the high-yielding seed is decreasing in risk aversion, the exception is in the 70% probability game where uptake of the high-yielding seed is higher among risk-averse individuals relative to those who are risk seeking. A Fisher's exact test is used to confirm whether there is a relationship between the type of seed chosen in the framed games and risk attitudes. The results indicate that there is a significant relationship between choice of seed and risk attitudes in both the 50% and 70% games (30% risk & insurance games: $p\text{-value} = 0.837$; 50% risk & insurance games: $p\text{-value} = 0.031$; 70% risk & insurance games: $p\text{-value} = 0.060$).

Figure 3. Uptake of each option in series 1 (*TS* vs. *HYL*), by risk category



To further analyse participants' uptake decisions in series 1 (*TS* vs. *HYL*), a random-effects logit regression is estimated, the results of which are reflected in table 7. The dependent variable is a dummy variable reflecting the choice of traditional seeds as opposed to the high-yielding seeds. Participants' *CE ratios* have been incorporated into the model as an explanatory variable; the remaining explanatory variables are familiar. Positive coefficients indicate an increase in the likelihood of choosing traditional seeds.

The results indicate that participants are less likely to opt for traditional seeds when the probability of good rain is 70% (relative to 50%) ($p = 0.010$), signalling the importance of production risk on input choice. Furthermore, the coefficient of *CE ratio* indicates that individuals who are *more* risk averse are more likely to opt for traditional seeds, but this result is only significant at the 10% level ($p = 0.076$).

Table 7. Regression analysis of participants' uptake decisions in series 1 (TS vs. HYL)

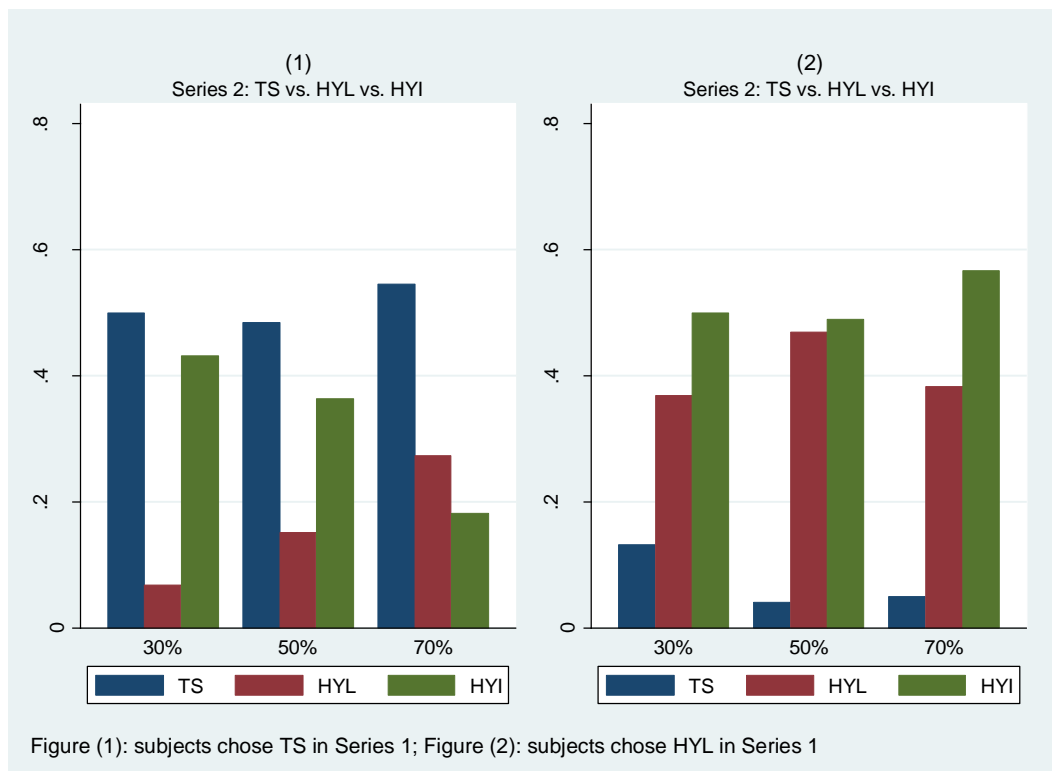
VARIABLES	COEFFICIENT
Session1	-0.375 (1.228)
Session2	0.434 (1.124)
Prob. good rain (30%)	0.634 (0.542)
Prob. good rain (70%)	-1.713* (0.667)
CE ratio	1.575+ (0.888)
Age > 50	0.892 (1.254)
High School	-0.512 (1.152)
HH income > R500	-0.826 (1.117)
Female	1.536 (0.938)
Constant	-2.942+ (1.693)
ll	-95.48
df_m	9
chi2	16.03
P > chi2	0.0663

Notes:

- Dependent variable is uptake of traditional seeds in T1 (TS vs. Uninsured loan)
- Positive coefficients indicate an increase in the likelihood of choosing traditional seeds.
- Robust standard errors (in parenthesis) clustered on the subject level
- ** p<0.01, * p<0.05, + p<0.1
- A higher *CE ratio* denotes higher risk aversion

The second objective of this study is to determine whether individuals who selected traditional seeds in series 1 (*TS vs. HYL*) are more likely to opt for high-yielding seeds in series 2 (*TS vs. HYL vs. HYI*) when the option of insurance is available. As such, for the subsample of individuals who selected *traditional seeds* in series 1, part 1 in figure 4 reflects participants' choices in series 2. As demonstrated by the figure, the majority of individuals opt for either traditional seeds or high-yielding seeds with loan and insurance. For the sub-sample of individuals who selected high-yielding seeds in series 1, part 2 in figure 4 indicates that the majority of these individuals opted either into high-yielding seeds (with loan) or high-yielding seeds (with loan and insurance) in series 2.

Figure 4. Uptake of each option in series 2 according to choice in Series 1



Notes:

- TS: Traditional seeds
- HYL: High-yielding seeds with loan
- HYI: High-yielding seeds with loan and insurance
- Figure (1) reflects distribution of choices of subjects who chose TS in Series 1 (*TS vs. HYL*)
- Figure (2) reflects distribution of choices of subjects who chose HYL in Series 2 (*TS vs. HYL vs. HYI*)

A two-sample proportions test is used to compare the proportion of subjects switching between the different options. Firstly, a comparison of the proportion of individuals who selected TS in both series 1 & 2 to the proportion who switched from HYL in series 1 to TS in series 2 confirms that, for all games, the proportions differ significantly from one another ($p < 0.01$ for 30%, 50% and 70% games). In other words, as expected, the proportion of subjects who stayed with their choice of TS is significantly larger than the proportion who switched from HYL (in series 1) to TS in series 2. Secondly, a comparison of the proportion of individuals who switched from TS to HYL relative to the proportion who opted for HYL in both series 1 and 2 indicates that the proportions differ significantly in the 30% and 50% games ($p < 0.01$ for 30%, 50% games). This results suggests that, of those opting for HYL in series 2, a larger proportion initially selected HYL in series 1 (as opposed to TS). Finally, a comparison of the proportion

of individuals who switched from TS to HYI relative to the proportion who switched from HYL to HYI suggests that only in the 70% game do these proportions differ significantly (30% and 50% games: $p > 0.05$; 70% game: $p < 0.01$). Broadly and taken together, these results imply that, firstly, of those who chose TS in series 2, a greater proportion initially chose TS in series 1 and, secondly, of those who chose HYL in series 2, a greater proportion initially chose HYL in series 1. The results for HYI are less clear and suggest that participants opting for HYI in series 2 are equally likely to have selected either TS or HYL in series 1.

Table 8 reflects the results of random-effects ordinal panel regressions. The dependent variable is a three level variable that ranks the seed options in series 2 according to the hierarchy of their associated standard deviations (1 = HYL, 2 = HYI, 3 = TS). The results are displayed as proportional odds ratios.

In regression 1, the familiar *CE ratio* has been included. The coefficient for *CE ratio* confirms that as risk aversion increases, participants are more likely to opt into TS relative to HYI and HYL, however, this results is only significant at the 10% level ($p = 0.099$). The coefficient indicates that for a one unit increase in the CE ratio, the odds of choosing TS versus the combined HYI and HYL categories are 5 times greater. In regression 2, as opposed to the CE ratio, we include a dummy variable for participants' choices in series 1 (*TS vs. HYL*), where the variable equals 1 if participants selected TS. The coefficient indicates that participants who selected TS in series 1 are 8 times more likely to again opt for TS in series 2 versus the combined HYI and HYL categories ($p = 0.000$). We replicate the regression in equation 3, but this time for a subsample of individuals with a CE ratio > 0.5 (in other words, a subsample of individuals who are risk averse). Again we find that risk averse individuals who selected TS in series 1 are more likely to choose TS again in series 2 relative to the combined HYI and HYL categories.

Table 8. Regression analysis of participants' uptake decisions in series 2 (TS vs. HYL vs. HYI)

VARIABLES	(1)	(2)	(3)
Session1	4.202 (5.273)	4.056 (4.376)	3.079 (3.267)
Session2	3.196 (3.107)	2.598 (2.248)	1.515 (1.264)
Prob. good rain (30%)	2.303* (0.886)	1.909+ (0.704)	2.106+ (0.906)
Prob. good rain (70%)	0.613 (0.279)	0.908 (0.413)	0.997 (0.502)
CE ratio	5.267+ (5.308)	-	-
TS in series 1		8.112** (4.875)	8.133** (5.412)
Age > 50	0.503 (0.541)	0.475 (0.420)	0.680 (0.660)
High School	0.427 (0.412)	0.537 (0.440)	0.482 (0.371)
HH income > R500	0.236 (0.286)	0.325 (0.341)	0.353 (0.391)
Female	4.651 (4.548)	3.090 (2.590)	2.405
Observations	189	189	148
ll	-155.1	-150.7	-125.5
df_m	9	9	9
chi2	18.76	25.71	20.70
p	0.0273	0.00228	0.0141

Notes:

- Results reported as odds ratios
- Robust standard errors (in parenthesis) clustered on the subject level
- Ordinal panel regression (dependent variable: 1=HYL, 2=HYI, 3=TS)

7 Discussion

The link between production (and thus consumption) risk and adoption perpetuates the idea of a risk-induced poverty trap in which poorer households that are unable to adequately insulate themselves from consumption risk avoid some of the possible downside risk by opting for the lower return afforded by lower risk agriculture, rather than the potentially higher returns engendered by use of modern inputs (Dercon and Christiaensen 2011). As expected, risk aversion is often considered to be a key element in this poverty-trap cycle, as poor individuals who are risk-averse – and thus unwilling to invest in potentially profitable but riskier modern inputs – remain poor, while wealthier individuals who are in a position to insulate themselves

from risk will benefit from technological innovations (Mosley and Verschoor 2005). In these circumstances, insurance products that reduce the consumption risks associated with the use of modern inputs would, in theory, promote technology diffusion and help break the poverty-trap cycle.

However, the argument that risk aversion perpetuates a cycle of poverty needs to be substantiated through empirical evidence. In this setting, Giné and Yang (2009) discuss the likely correlation between access to credit, on the one hand, and willingness to take on risk (for example, by investing in a new input) on the other. While a number of studies show a positive correlation between wealth and adoption of technology (Croppenstedt *et al.* 2003, Cole *et al.* 2013a, Giné *et al.* 2008, Chirwa 2005, Dercon and Christiaensen 2011), the dynamics at work are not always clear. For example, while wealthy households will have greater access to credit relative to less wealthy households, they are also more likely to invest in new inputs because they can better bear the associated risk burden (Giné and Yang 2009). However, some studies find adoption and risk aversion to be negatively correlated (Liu 2008, Simtowe 2006). These results motivate our effort to disentangle the effect of credit constraints from risk preferences. To do so, we run a series of framed field experiments with a sample of South African subsistence farmers. In the first treatment, farmers choose between traditional agriculture (framed as traditional seeds) and investing in a new farming input that requires them to take out a loan (framed as high-yielding seeds with a loan). In a subsequent treatment, farmers make this decision again, but are provided with a third option of investing in high-yielding seeds with a loan and rainfall insurance. We also elicit farmers' risk preferences using simple lottery tasks for real monetary prizes.

By omitting an insurance option from the initial treatment of the insurance games, we are able to examine whether the provision of the simulated insurance product induces risk-averse subjects to move from low risk, low return traditional agriculture to use of riskier but potentially more profitable high-yielding seeds. As such, we are able to assess whether the availability of insurance products, which reduce (but do not remove) the consumption risks associated with the use of modern inputs, promotes technology diffusion and helps to break the poverty-trap cycle by encouraging individuals (and particularly risk-averse individuals) to opt into riskier but potentially more profitable farming strategies.

This laboratory approach ensures that we are able to isolate the impact of risk preferences and avoid other confounding factors that are likely determinants of insurance uptake, such as credit constraints (Croppenstedt *et al.* 2003, Cole *et al.* 2013a, Giné *et al.* 2008, Chirwa 2005, Dercon and Christiaensen 2011) and issues around familiarity with insurance and trust of insurance companies (Giné *et al.* 2008).

Overall, the results of the experiment lend empirical weight to the poverty-trap argument. First, a high degree of risk aversion is evident among the sample. Akay *et al.* (2012), who conducted a similar experiment with farmers in Ethiopia, found comparably high levels of risk aversion in their sample. Secondly, irrespective of the level of production risk (the probability of good rainfall was varied at different probability levels), risk-averse individuals are more likely to opt into traditional agriculture (reflected as traditional seeds in the experiment) and are less likely to use modern farming inputs that require financing (high-yield varieties) despite the availability of insurance.

The results confirm the long-held contention in the literature that pure risk preferences are a determinant in farmers' adoption decisions. However, they further indicate that index insurance is not a panacea when it comes to promoting technology diffusion.

The insurance product in this experiment was designed to reduce the loss experienced by the participants in the event of crop failure, but did not remove this loss entirely, and no doubt this impacted the results. This design reflects the idea that index insurance does not completely remove production and consumption risk, but rather reduces or minimises the risk. The laboratory experiment reflects the reality that index insurance does not remove all risk from the production process; specifically, even if a particular index insurance product completely removed the production risk associated with rainfall variability, arguably the most important source of production risk for farmers in developing countries, it would not pay out for crop damage derived from other factors (such as pests), known as basis risk (Barrett *et al.* 2007). Thus, in order to overcome risk aversion among poor individuals stuck in the poverty cycle and to facilitate the uptake of insurance products, basis risk and residual production risk not accounted for by the insurance product need to be targeted.

References

- Akay, A. Martinsson, P., Medhin, H., Trautmann, S. 2012. Attitudes toward uncertainty among the poor: an experiment in rural Ethiopia. *Journal of Theory and Decision*, 73: 453-464.
- Andersen, S., Harrison, G., Lau, M., Rutström, E., 2008, "Eliciting Risk and Time Preferences," *Econometrica*, 76:583 - 618.
- Andersen, S., Harrison, G., Lau, M., Rutström, E., 2010, "Behavioral econometrics for psychologists," *Journal of Economic Psychology*, 31:553 - 576.
- Barrett, C., Barnett, M., Carter, S., Chantarat, J., Hansen, A., Mude, D., Osgood, J., Skees, C. 2007. Index Insurance for Climate Risk Management & Poverty Reduction. Adapted from IRI Technical Report 07-03, Working Paper - Poverty Traps and Climate Risk: Limitations and Opportunities of Index-Based Risk.
- Brick, K., Visser, M., Burns, J. 2012. Risk Aversion: Experimental Evidence from South African Fishing Communities. *American Journal of Agricultural Economics*, 94(1): 133 – 152.
- Chirwa, E. 2005. Adoption of fertiliser and hybrid seeds by smallholder maize farmers in Southern Malawi. *Development Southern Africa*, 22(1): 1-12.
- Cole, S., Giné, X., Tobacman, J., Topalova, P., Townsend, R., Vickery, J. 2013a. Barriers to Household Risk Management: Evidence from India. *American Economic Journal: Applied Economics*, 5(1): 104–135.
- Cole, S., Giné, X., Vickery, J. 2013b. How Does Risk Management Influence Production Decisions? Evidence from a Field Experiment. World Bank Policy Research Working Paper No. 6546.

- Cornejo, J., McBride, W., El-Osta, H., Heimlich, R., Soule, M., Klotz-Ingram, C., Daberkow, S., Goodhue, R., Alexander, C. 2002. Adoption of Bioengineered Crops. Agricultural Economic Report No. 810.
- Croppendtedt, A., Demeke, M., Meschi, M. 2003. Technology Adoption in the Presence of Constraints: the Case of Fertiliser Demand in Ethiopia. *Review of Development Economics*, 7(1): 58-70.
- Dercon, S., Christiaensen, L. 2011. Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. *Journal of Development Economics*, 96: 159-173.
- Duflo, E., Kremer, M., Robinson, J. 2011. Nudging Farmers to Use Fertiliser: Theory and Experimental Evidence from Kenya. *American Economic Review*, 101: 2350-2390.
- Engle-Warnick, J., Escobal, J., Laszlo, S. 2007. Ambiguity Aversion as a Predictor of Technology Choice: Experimental Evidence from Peru. CIRANO Scientific Series, 2007s-01.
- Feder, G., Just, R., Zilberman, D. 1985. Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change*, 33(2): 255-298.
- Galarza, F., 2009, "Choices under Risk in Rural Peru," MPRA Paper No. 17708.
- Giné, X., Yang, D. 2009. Insurance, credit and technology adoption: Field experimental evidence from Malawi. *Journal of Development Economics*, 89:1-11.
- Giné, X., Townsend, R., Vickery, J. 2008. Patterns of Rainfall Insurance Participation in Rural India. *The World Bank Economic Review*, 22(3): 539-566.
- Harrison, G., Rustrom, E., 2008, "Risk Aversion in the Laboratory," *Research in Experimental Economics*, 12:41 – 196.
- Hazell, P., Anderson, J., Balzer, N., Clemmensen, A., Hess, U., Rispoli, F. 2010. Potential for Scale and Sustainability in Weather Index Insurance for Agriculture and Rural

- Livelihoods. International Fund for Agricultural Development and World Food Programme. Rome, March.
- Holt, C., Laury, S., 2002, "Risk Aversion and Incentive Effects," *The American Economic Review*, 92(5):1644 – 1655.
- Humphrey, S., Verschoor, A., 2004, "Decision-making Under Risk among Small Farmers in East Uganda," *Journal of African Economies*, 13(1):44 – 101.
- Jacobson, S., Petrie, R.. 2008. Learning from Mistakes: What do Inconsistent Choices Over Risk Tell Us? *Journal of Risk and Uncertainty*, 38:143–158.
- Karlan, D., Osei, R., Osei-Akoto, I., Udry, C. 2012. Agricultural decisions after relaxing credit and risk constraints. NBER Working Paper Series, Working Paper 18463. National Bureau of Economic Research, Cambridge.
- Liu, E., 2008, "Time to Change What to Sow: Risk Preferences and Technology Adoption Decisions of Cotton Farmers in China, Princeton University Working Paper No. 526.
- Mobarak A., Rosenzweig, M. 2012. Selling Formal Insurance to the Informally Insured. Department of Economics, Yale University. Economic Department Working Paper No. 97, Economic Growth Center Discussion Paper No. 1007.
- Moore, E., Eckel, C. 2006. Measuring Ambiguity Aversion. Available online.
- Mosley, P., Verschoor, A., 2005, "Risk Attitudes and the Vicious Circle of Poverty," *The European Journal of Development Research*, 17(1):59 – 88.
- Patt, A., Suarez, P., Hess, U. 2010. How do small-holder farmers understand insurance, and how much do they want it? Evidence from Africa. *Global Environmental Change*, 20: 153-161.
- Simtowe, F. 2006. Can Risk-aversion towards fertiliser explain part of the non-adoption puzzle for hybrid maize? Empirical evidence from Malawi. MPRA Paper No. 1241.

Tanaka, T., Camerer, C., Nguyen, Q., 2010, "Risk and Time Preferences: Linking Experimental and Household Survey Data from Vietnam," *American Economic Review*, 100(1):557 – 571.

Univeristy of Cape Town

Appendix A. Decision sheet

Table A1. 30% gamble

	Option 1	✓		Option 2	✓
[1]	R3 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[2]	R4 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[3]	R5 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[4]	R6 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[5]	R7 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[6]	R8 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[7]	R9 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[8]	R10 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[9]	R11 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[10]	R12 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[11]	R13 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[12]	R14 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[13]	R15 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[14]	R16 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[15]	R17 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[16]	R18 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[17]	R19 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[18]	R20 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[19]	R21 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[20]	R22 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[21]	R23 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[22]	R24 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[23]	R25 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[24]	R26 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>

Appendix B. Instructions (excerpt)

Risk games

Game 1: 30% probability of earning R50

I am now going to explain the rules of the first game. This poster is a large version of the sheet of paper that is in front of you.

In this game, you must choose between 2 options: Option 1 and Option 2 [REFER TO POSTER].

You must show on the answer sheet in front of you, **for each row**, whether you choose Option 1 or Option 2.

This is very important: if you choose Option 1, you will earn a sure amount of money!

If you choose Option 2, the amount of money you earn depends on this spinning wheel. And, it depends on whether the arrow lands on white or black.

Because this is SO important, let me say it again: if you choose Option 1, you will earn a sure amount of money. But, if you choose Option 2, the amount of money you earn depends on this spinning wheel. And, it depends on whether this arrow lands on white or black [DEMONSTRATE BY MOVING THE ARROW].

This is what will happen if you choose Option 2:

One of you will come up and spin the arrow. If your arrow lands on white, you will earn nothing. If the arrow lands on black, you will earn R50. DEMONSTRATE BY SPINNING THE ARROW: the arrow has landed on [white, black]. This means you would have earned [nothing, R50].

[SPINNING WHEEL REPRESENTING 30%]: Now, as you can see, the white area is much bigger than the black area. So this means that, if you choose Option 2 and spin the wheel, there is a bigger chance of the arrow landing on white than there is of it landing on black. So there is a bigger chance of you earning nothing than there is of you earning R50.

OK, let's look at the poster:

In row 1:

If you choose Option 1 [GESTURE TO OPTION 1 ON POSTER], you will earn R3 for sure. You won't have to spin the arrow.

But, if you choose Option 2 [GESTURE TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn R50.

In row 2:

If you choose Option 1 [GESTURE TO OPTION 1 ON POSTER], you will earn R4 for sure. You won't have to spin the arrow.

If you choose Option 2 [GESTURE TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn R50.

In row 3:

If you choose Option 1 [GESTURE TO OPTION 1 ON POSTER], you will earn R5 for sure. You won't have to spin the arrow.

If you choose Option 2 [GESTURE TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn R50.

In row 10:

If you choose Option 1 [GESTURE TO OPTION 1 ON POSTER], you will earn R12 for sure. You won't have to spin the arrow.

If you choose Option 2 [GESTURE TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn R50.

In row 15:

If you choose Option 1 [GESTURE TO OPTION 1 ON POSTER], you will earn R17 for sure. You won't have to spin the arrow.

If you choose Option 2 [GESTURE TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn R50.

In row 20:

If you choose Option 1 [GESTURE TO OPTION 1 ON POSTER], you will earn R22 for sure. You won't have to spin the arrow.

If you choose Option 2 [GESTURE TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn R50.

In row 24:

If you choose Option 1 [GESTURE TO OPTION 1 ON POSTER], you will earn R26 for sure. You won't have to spin the arrow.

If you choose Option 2 [GESTURE TO OPTION 2 ON POSTER], your payoff will depend on what colour the arrow lands on. If the arrow lands on white, you earn nothing, but if it lands on black, you earn R50.

[IMPORTANT TO STRESS:]

OK, now this is very important! As you can see, the sure payoff you earn from Option 1 **increases** as you go down the rows. It has increased from R3 in row 1 to R26 in row 24 [GESTURE TO THE POSTER AS YOU SAY THIS].

But, the payoff to Option 2 **stays the same throughout the whole game!** In the first row, if you choose Option 2, you will **either** earn nothing if the arrow lands on white, or you will earn R50 if the arrow lands on black. In row 10, if you choose Option 2, you will **either** earn nothing if the arrow lands on white, or you will earn R50 if the arrow lands on black. In row 24, if you choose Option 2, you will **either** earn nothing if the arrow lands on white, or R50 if the arrow lands on black. [GESTURE DOWN POSTER WHILE SAYING THIS]

Let's do an example: **[NOW YOU ACTUALLY DRAW ON THE POSTER]**

In row 1, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn R3 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn R50. Let's pretend you choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].

In row 2, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn R4 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn R50. Let's pretend you choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].

In row 3, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn R5 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn R50. Let's pretend you choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].

In row 4, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn R6 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn R50. Let's pretend you

choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].

In row 5, you have 2 options. You can choose Option 1 or Option 2. If you choose Option 1, you will earn R7 for sure. If you choose Option 2, your payoff will depend on what colour the arrow lands on. If it lands on white, you will earn nothing. If it lands on black, you will earn R50. Let's pretend you choose Option 2 – so you want to spin the arrow. Then make a tick in the right box like this [MAKE A TICK IN THE RIGHT BOX].

Let's pretend you choose Option 2 all the way down to row 8. **TICK UP TO ROW 8.**

Now, in row 9, you choose Option 1. [NOW MAKE A TICK IN THE LEFT COLUMN]

So in row 9 you **switch to** Option 1. Remember that you always get a sure return with Option 1, so you will have a sure payoff of R11. So at row 9, you prefer the sure payoff of R11 you get with Option 1, as opposed to taking a chance with Option 2 on where the arrow lands and earning either R0 or R50. Then when we go to row 10, you will now earn R12 if you pick Option 1 – the sure payoff is now even higher. And in row 11 you will earn even more with Option 1 – you will earn R13. In row 12, Option 1 will give you even more money – you will get a sure payoff of R14. So your earnings from Option 1 are getting higher and higher as you go down the rows. But with Option 2, you always have the **same chance** of earning R0 or R50 **depending** on where the arrow lands.

So, going back to your choice, if you liked Option 1 more in row 9 when you had a sure payoff of R11, then you would also like Option 1 in rows 10, 11, 12, 13, 14, all the way to 20 as the payoffs get higher and higher.

So (this is VERY important), once you pick Option 1, you will pick Option 1 for the rest of the rows!
[REPEAT THIS POINT A FEW TIMES]

[Note: Important they know that once they pick Option 1, they must stay with Option 1 for the rest of the rows. Once they have filled in the practice sheet, we will go around and check that respondents have not made a mistake.]

[IMPORTANT] You are not going to be paid for each row. I have here 24 numbered balls. I am going to now put these balls into this bag [PUT THE BALLS INTO A BAG]. Once we have played the game and you have made a choice between Option 1 and Option 2 for each row, we will use this bag to decide which row will be played for money. **One of you** will pull a ball out of this bag. If the ball has the number 1 on it, we will play row 1 for money. If the ball has a 2 on it, we will play row 2 for money. If the ball has a number 24 on it, we will play row 24 for money.

After we know which row we are playing for money, one of you will then come up and spin the arrow.

Does anyone have any questions before we start?

Because this is the first game, we are going to first do a practice round. So this round won't count for money – but is just to make sure that you understand how the game works.

Ok, let's start. Please write the number we gave you at the start of the experiment on the sheet where it says experiment number [GESTURE TO WHERE THEY MUST PUT THEIR NUMBER].

For **each** row in the sheet in front of you, indicate whether you would like to choose Option 1 and receive a sure amount of money, or whether you would like to choose Option 2 and spin the arrow.

Ok, now we are going to play the game for real. Please write the number we gave you at the start of the experiment on the sheet where it says experiment number [GESTURE TO WHERE THEY MUST PUT THEIR NUMBER].

For **each** row in the sheet in front of you, indicate whether you would like to choose Option 1 and receive a sure amount of money, or whether you would like to choose Option 2 and spin the arrow.

Univeristy of Cape Town

Game 1

Experiment number: _____

	Option 1	✓		Option 2	✓
[1]	R3 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[2]	R4 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[3]	R5 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[4]	R6 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[5]	R7 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[6]	R8 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[7]	R9 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[8]	R10 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[9]	R11 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[10]	R12 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[11]	R13 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[12]	R14 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[13]	R15 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[14]	R16 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[15]	R17 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[16]	R18 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[17]	R19 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[18]	R20 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[19]	R21 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[20]	R22 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[21]	R23 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[22]	R24 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[23]	R25 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>
[24]	R26 for sure	<input type="checkbox"/>	OR	Spin the wheel: ○ R0 / ● R50	<input type="checkbox"/>

INSURANCE GAMES: TRADITIONAL SEEDS AND LOAN

Game 1

30% chance of good rain

I want you to imagine that this game represents a **farming season**. And, at the start of this farming season, you have to decide **what type of seed you are going to use**.

The amount of money that you can earn or lose depends on what type of seed you choose to plant and how much it rains!

[INTRODUCE RAINFALL]

I want to explain this table, which you have on the answer sheet in front of you [REFER TO POSTER AS YOU TALK].

Now, these columns tell you about the rainfall. In the blue column, rainfall is good. In the red column, rainfall is low.

So, I said earlier that you need to choose what type of seed to plant. You must choose between traditional seeds and improved seeds [REFER TO POSTER].

	Rainfall	
	Good	Low
Traditional seeds	10	0
Improved seeds with loan	100	-35

[TRADITIONAL SEEDS]

Let's start with traditional seeds. Traditional seeds are the seeds that you have always used. You save these seeds every year, so they do not cost you anything. Your harvest is lower with traditional seeds than with other seeds. But the good thing about traditional seeds is that your harvest will be quite certain.

You can see on the poster, if you use traditional seeds:

When the rains are good: you will earn R10.

When the rains are low: you will earn nothing.

So if you choose to plant traditional seeds, **you know that you will earn a maximum of R10 and a minimum of nothing** [GESTURE TO POSTER]

[IMPROVED SEEDS]

Now let's talk about improved seeds.

You have heard about these seeds from other farmers who have started using them, but **you have not used these seeds yourself**. The few farmers who have started using these new seeds have told you that the seeds can really increase your harvest when the rains are good. **But these seeds do very badly when the rains are low.**

[IMPROVED SEEDS WITH LOAN]

If you want to try improved seeds, you need to buy them. But because they are expensive, you will need to take out a loan at the bank. **So that is why you have an option here of: improved seeds with loan** [REFER TO THE OPTION ON THE POSTER].

In order to buy the improved seeds, you need to take out a loan of R35 at the bank.

This loan needs to be paid back at the end of the game.

The payoffs in the table show you what you are left with AFTER you have paid back the loan [STRESS THIS POINT].

If you buy improved seeds using a loan from your local bank and the rains are good, **after paying back the bank loan**, you are left with R100.

But, just like the traditional seeds, improved seeds do not do well when rainfall is low. But even when rains are low, you still need to pay the bank back for the R35 loan. So now, instead of earning nothing when the rains are low, you still have to pay R35 back to the bank. So, when the rains are low, you actually **LOSE R35. Remember, this money will be taken out of the R180 you have already earned for participating.**

[EXPLAIN HOW THE RAINFALL WORKS]

OK, but how do you know if there is good or bad rainfall?

We are going to use this spinning wheel.

If the arrow lands on blue – then there is good rain.

If the arrow lands on red – there is low rain.

Let me say that again... [REPEAT].

[SPINNING WHEEL REPRESENTING 30% CHANCE OF GOOD RAIN]: As you can see, the arrow can land on blue or red. If the arrow lands on blue, rainfall is good. If the arrow lands on red, rainfall is low. The blue area is **much smaller** than the red area. So there is a **much bigger** chance of the arrow landing on red than there is of the arrow landing on blue. So there is a **much bigger chance** that rains will be low.

[EXAMPLE] Ok, let's do an example. It is the start of the farming season, and you must decide if you want to use **traditional seeds** or **improved seeds**.

If you want to use the traditional seeds, you do not have to worry about taking out a loan from the bank. If the rains are good, you will earn R10. If the rains are low, you will earn nothing.

If you decide to use improved seeds, you **will have to** take a loan from your local bank. **You need to borrow R35 from the bank in order to buy the improved seeds.** Remember that you have to pay this loan back at the end of the game.

If the rains are good, after paying back the loan, you are left with R100. If the rains are low, you still have to pay the bank back the R35 you borrowed. So now, instead of earning nothing, when the rains are low, you actually LOSE R35.

Let's pretend that you decide to plant traditional seeds. You would make a tick on your answer sheet like this [APPROPRIATE MARK ON ANSWER SHEET]. Now let's see what your payoff would be. [SPIN THE WHEEL]. OK, so the arrow landed on [blue, red] which means that the rains are [good, low]. This means you would earn [R10, R0].

Let's try another example. Let's pretend that you decide to plant improved seeds by getting a loan of R35 from the bank. So then you tick this option on your answer sheet – improved seeds with loan [APPROPRIATE MARK ON ANSWER SHEET]. Now let's see what your payoff would be. [SPIN THE WHEEL]. OK, so the arrow landed on [blue, red] which means that the rains are [good, low]. So **after paying back the loan to the bank**, you would [earn R100, lose R35] [POINT TO CORRECT COLUMN IN POSTER]. If the rains had been [good, low], **after paying back the loan**, you would have [earned R100, lost R35].

So how will the game work? You are going to make your decisions on the answer sheet. When you are finished, someone is going to come and collect your answer sheets. Then someone will spin the arrow so we know what the level of rainfall is.

Does anyone have any questions before we start?

Let's start. Please write the number we gave you at the start of the experiment on the sheet where it says experiment number [GESTURE TO WHERE THEY MUST PUT THEIR NUMBER].

On the answer sheet in front of you, please indicate whether you would like to plant traditional seeds **or** improved seeds with a loan. **You can only pick one of these options.**

Game 1

Experiment number: _____

	Rainfall	
	Good	Low
Traditional seeds	10	0
Improved seeds with loan	100	-35

Please choose the option that you prefer from the 2 options listed below.

Note: Only choose one option

Type of seed:	Your choice (✓)
Traditional seeds	
Improved seeds with loan	

INSURANCE GAMES: TRADITIONAL SEEDS, LOAN & INSURANCE

Game 1

30% chance of good rain

The next set of games is similar to the games you have just played.

Once again, I want you to imagine that this game represents a **farming season**. And, at the start of this farming season, you have to decide **what type of seed you are going to use**.

The amount of money that you can earn or lose depends on what type of seed you choose to plant and how much it rains!

[INTRODUCE RAINFALL]

Just like before, these columns tell you about the rainfall. In the blue column, rainfall is good. In the red column, rainfall is low.

Just like before, you need to choose what type of seed to plant. You must choose between traditional seeds and improved seeds [REFER TO POSTER].

	Rainfall	
	Good	Low
Traditional seeds	10	0
Improved seeds with loan	100	-35
Improved seeds with loan & insurance	80	-10

[TRADITIONAL SEEDS]

Let's remind ourselves about traditional seeds:

Traditional seeds are the seeds that you have always used. You save these seeds every year, so they do not cost you anything. Your harvest is lower with traditional seeds than with other seeds.

But the good thing about traditional seeds is that your harvest will be quite certain.

You can see on the poster, if you use traditional seeds: When the rains are good, you will earn R10. When the rains are low, you will earn nothing.

[IMPROVED SEEDS]

Now let's talk about improved seeds.

You have heard about these seeds from other farmers who have started using them, but **you have not used these seeds yourself**. The few farmers who have started using these new seeds have told you that the seeds can really increase your harvest when the rains are good. **But these seeds do very badly when the rains are low.**

[IMPROVED SEEDS WITH LOAN]

If you want to try improved seeds, you need to buy them. But because they are expensive, you will need to take out a loan at the bank. **So that is why you have an option here of improved seeds with loan** [REFER TO THE OPTION ON THE POSTER].

In order to buy the improved seeds, you need to take out a loan of R35 at the bank.

This loan needs to be paid back at the end of the game.

The payoffs in the table show you what you are left with AFTER you have paid back the loan [STRESS THIS POINT].

If you buy improved seeds using a loan from your local bank and the rains are good, **after paying back the bank loan**, you are left with R100.

But, just like the traditional seeds, improved seeds do not do well when rainfall is low. But even when rains are low, you still need to pay the bank back for the R35 loan. So now, instead of earning nothing when the rains are low, you still have to pay R35 back to the bank. So, when the rains are low, you actually LOSE R35. **Remember, this money will be taken out of the R180 you have already earned for participating.**

[IMPROVED SEED WITH LOAN AND INSURANCE:]

But now there is another way to buy improved seeds!

Now, in addition to the loan, you can also buy insurance. That is why we have this option: improved seeds with loan and insurance [POINT TO POSTER].

Buying insurance is a way to protect your income and reduce your losses when the rains are low.

We will call this insurance “rainfall insurance.” **You can buy rainfall insurance for R20.**

I am now going to explain how the rainfall insurance works.

If you want to buy improved seeds, you need to take a loan of R35 from the bank in order to buy the seeds. You now also have an option of **paying an extra R20** to buy rainfall insurance.

So what do you get if you spend **an extra R20** and buy the insurance?

If the rains are good, you don't get anything back from the insurance company. This is because your crops received enough rainfall. So, even though you have spent R20 on insurance, if the rains are good, you do not get any money back from the insurance company.

If the rains are low, you will get money back from the insurance company. The insurance company will give you R45 back. The insurance company gives you money back as if your crops had received enough rainfall.

Ok, so if you decide to buy improved seeds with a loan AND insurance, it becomes **even more expensive to buy improved seeds**. You will need to pay the bank the R35 you have borrowed. You will also need to pay the insurance company R20 for the insurance.

Let's look at what you could earn if you choose to buy improved seeds with insurance. These payoffs show you how much money you are left with AFTER you have paid back the loan and paid for the insurance. The payoffs include any money that you get back from the insurance company.

Let's look at what you will earn if the rains are good. If you buy improved seeds with a loan and insurance, and the rains are good, after paying back the loan and paying for the insurance, you will earn R80.

If you had just bought improved seeds with a loan and had decided not to buy the insurance, you would have earned R100 [POINT TO THIS ON POSTER]. But now, you spent **an extra** R20 on the insurance. So now, if the rains are good, you will only earn R80

Remember, even though you have spent R20 on the insurance, you don't get any money back from the insurance company when the rains are good.

OK, let's look at what you will earn if the rains are low.

Now you have still spent R20 on insurance. But, because the rains are low, you get money back from the insurance company. You get R45 back from the insurance company. So, if you buy improved seeds and a loan, and the rains are low, you will lose R10.

If you had bought the improved seeds without the insurance, and the rains were low, you would have lost R35. **But now you only lose R10. This is because you have got money back from the insurance company.**

[EXPLAIN HOW THE RAINFALL WORKS]

OK, but how do you know if there is good or bad rainfall?

We are going to use this spinning wheel.

If the arrow lands on blue – then there is good rain.

If the arrow lands on red – there is low rain.

Let me say that again... [REPEAT].

[SPINNING WHEEL REPRESENTING 30% CHANCE OF GOOD RAIN]: As you can see, the arrow can land on blue or red. The blue area is much smaller than the red area. So there is a much bigger chance of the arrow landing on red than there is of the arrow landing on blue. So there is a much bigger chance of there being low rain than there is of there being good rain.

[EXAMPLE] Ok, let's do an example. It is the start of the farming season, and you must decide if you want to use **traditional seeds** or **improved seeds**.

If you want to use the traditional seeds, you do not have to worry about taking out a loan from the bank. If the rains are good, you will earn R10. If the rains are low, you will earn nothing.

If you decide to use improved seeds, you **will have to** take a loan from your local bank. And you have to pay this loan back to the bank. You can also decide whether or not you would like to take out insurance.

Let's look at the first option, which is to buy improved seeds with a loan only. If the rains are good, after paying back the loan, you are left with R100. If the rains are low, after paying back the loan of R35 to the bank, you lose R35.

Your other option is to buy the improved seeds with a loan, **but to pay an extra R20 and buy insurance**. Remember, you pay the R20 for the insurance regardless of whether the rain is good or low. And you get money back from the insurance company **only when the rains are low**.

If you decide to buy insurance and the rains are good, after paying back the bank loan and paying for the insurance, you will earn R80. If you did not buy the insurance, you would have earned R100. **So your income is lower because you spent an extra R20 on the insurance.**

Now, let's look at what happens if you choose to buy insurance and the rains are bad. You pay R20 for the insurance, but you get R45 back from the insurance company. So now, if the rains are bad, **you only lose R10. But, if you had not bought the insurance, you would have lost R35.**

Let's pretend that you decide to plant traditional seeds. You would make a tick on your answer sheet like this [APPROPRIATE MARK ON ANSWER SHEET]. Now let's see what your payoff would be. [SPIN THE WHEEL]. OK, so the arrow landed on [blue, red] which means that the rains are [good, low]. This means you would earn [R10, R0].

Let's try another example. Let's pretend that you decide to plant improved seeds. But you **don't** want to buy insurance. So then you tick this option on your answer sheet – improved seeds with loan [APPROPRIATE MARK ON ANSWER SHEET]. Now let's see what your payoff would be. [SPIN THE WHEEL]. OK, so the arrow landed on [blue, red], which means that the rains are [good, low]. So, **after paying back the loan of R35**, you would have [earned R100, lost R35] [POINT TO

CORRECT COLUMN IN POSTER]. If the rains had been [good, low], **after paying back the loan**, you would have [earned R100, lost R35].

Let's try another example. Let's pretend you still want to buy improved seeds, **but you also want to buy insurance** So then you tick this option on your answer sheet – improved seeds with loan and insurance [APPROPRIATE MARK ON ANSWER SHEET]. Now let's see what your payoff would be. [SPIN THE WHEEL]. OK, so the arrow landed on [blue, red], which means that the rains are [good, low]. So, **after paying back the loan and paying an extra R20 for insurance**, you would [earn R80, lose R10] [POINT TO CORRECT COLUMN IN POSTER]. If the rains had been [good, low], after paying back the loan and paying an extra R20 for insurance, you would have [earned R80, lost R10].

So, how will the game work? You are going to make your decisions on the answer sheet. When you are finished, someone is going to come and collect your answer sheets. Then someone will spin the arrow so we know what the level of rainfall is.

Does anyone have any questions before we start?

Let's start. Please write the number we gave you at the start of the experiment on the sheet where it says experiment number [GESTURE TO WHERE THEY MUST PUT THEIR NUMBER].

On the answer sheet in front of you, please indicate whether you would like to plant traditional seeds **or** improved seeds with a loan **or** improved seeds with a loan and insurance. **You can only pick one of these options.**

Game 1

Experiment number: _____

	Rainfall	
	Good	Low
Traditional seeds	10	0
Improved seeds with loan	100	-35
Improved seeds with loan & insurance	80	-10

Please choose the option that you prefer from the 3 options listed below.

Note: Only choose one option

Type of seed:	Your choice (✓)
Traditional seeds	
Improved seeds with loan	
Improved seeds with loan and insurance	

Appendix C. CRRA parameters

For comparison with other studies, table C1 reflects the bounds on r implied by subjects' choices when a Constant Relative Risk Averse (CRRA) utility function (defined over the lottery prize) is assumed (Holt and Laury 2002, Andersen *et al.* 2008, Andersen *et al.* 2010, Harrison and Rutström 2008). The CRRA function is of the form $U(x) = (x^{1-r})/(1-r)$ where x is the lottery prize and r is the latent risk coefficient – where $r = 0$ indicates risk neutrality and $r > 0$ indicates risk aversion. Table C1 is interpreted as follows: highly risk averse subjects who selected Option 1 (safe choice) from row 1 (and therefore made 24 safe choices) reveal a CRRA estimate of greater than 0.572 in the 30% gamble, 0.485 in the 50% gamble and 0.541 in the 70% gamble. Risk averse subjects who switched from Option 2 (risky choice) to Option 1 (safe choice) in rows 2-5 (i.e., made between 20 and 23 safe choices) reveal a CRRA interval of between 0.410 and 0.572 in the 30% gamble, 0.375 and 0.485 in the 50% gamble and, finally, 0.438 and 0.541 in the 70% gamble. The proportion of subjects in each risk category is reflected in table C2, which confirms that the majority of participants made choices reflecting a high degree of risk aversion.

Table C1. Implied bounds of CRRA and associated risk classification



Switching row	# Safe choices	30% gamble	50% gamble	70% gamble	
10 – 13	12 – 15	$0.027 < r < 0.229$	$0.028 < r < 0.223$	$0.039 < r < 0.278$	Risk neutral/slightly risk averse
6 – 9	16 – 19	$0.229 < r < 0.410$	$0.223 < r < 0.375$	$0.278 < r < 0.438$	 Increasing degrees of risk aversion
2 – 5	20 – 23	$0.410 < r < 0.572$	$0.375 < r < 0.485$	$0.438 < r < 0.541$	
1	24	$0.572 < r$	$0.485 < r$	$0.541 < r$	

Table C2. Proportion of subjects in each risk category

Switching row	# Safe choices	30% gamble	50% gamble	70% gamble	
10 – 13	12 – 15	12%	12%	7%	Risk neutral/slightly risk averse
6 – 9	16 – 19	18%	9%	16%	 Increasing degrees of risk aversion
2 – 5	20 – 23	10%	16%	4%	
1	24	51%	49%	45%	

Conclusion

In the context of applications to both mitigation and adaptation, the four papers of this thesis consider: (i) self-interested use of equity preferences and, more so, the impact of material self-interest on cooperation in the negotiating process; (ii) the effect of heterogeneous mitigation costs on cooperation in meeting a domestic emission reduction target; (iii) the relationship between risk attitudes and choice of adaptation strategy in the context of uncertainty around the timing and severity of climate variability; and (iv), the relationship between risk attitudes and adaptation when proposed adaptive strategies have uncertain outcomes. The results are outlined below in reference to these broad categories:

(i) Self-interested use of equity preferences in multilateral climate negotiations and the impact of self-interest on the negotiating process

The first paper of this thesis “**What is fair? An experimental guide to climate negotiations**” considers one of the negotiating challenges prevalent in multilateral climate negotiations: namely, the potential for self-interested use of equity principles (where individuals’ use of equity principles reflects material self-interest as opposed to a genuine sense of fairness). To do so, a threshold public good game with a climate change framing is used, where groups of individuals, consisting of participants from the US, EU, China, India and SA, must collectively meet an emission reduction target (the threshold). In the first treatment, called the own nationality treatment, the participants choose between various equity principles when the cost ranking (in terms of contributions to the public good) of each principle is made explicit for each of their respective nationalities.

In line with the findings of other studies, choice of equity principle among American and Chinese players is found to be in line with material self-interest, with the majority of participants from both nationalities opting for burden-sharing principles that specify the smallest contributions to the public good of mitigation. This result, that choice of burden-sharing principle is (at least partly) derived from material self-interest, is important in the context of multilateral climate negotiations where the equity principle that an agent adheres to will likely affect or shape the negotiating process (and by extension, the negotiation outcome).

Against this background, this experiment further examines the *impact* of self-interest on the negotiating process. To do so, in a second treatment, while participants must once again choose between the various burden-sharing principles, they do so from behind a veil of ignorance, where they no longer know which payoff function is applicable to them. In this treatment, the results indicate that both American and Chinese participants are more likely to opt for equity principles that specify larger contributions to the public good. Additionally, the results signal that the self-interested use of equity principles impedes success in meeting the specified threshold (in terms of the framing: the emission reduction target). While initially around 37% of groups met the target; this proportion increased significantly to almost 57% when participants selected equity preferences from behind the veil of ignorance.

Within the context of ongoing climate policy, the voluntary emission reduction pledges under the Copenhagen Accord (a pledge and review system of voluntary emission reduction targets) fall far short of guaranteeing that the target of keeping temperature warming to below 2 °C will be met. The results of this article indicate that self-interested use of equity principles explains (at least in part) this gap between the voluntary pledges and scientific threshold: specifically, negotiators are able to make pledges that are more in line with their own material self-interest (and that collectively are insufficient to meet the threshold) while still legitimising their position through the use of equity principles.

(ii) The effect of heterogeneous mitigation costs on cooperation in meeting a domestic emission reduction target

The current model for tackling climate change is a top-down approach in terms of which emission reduction targets are first negotiated at multilateral climate talks and then implemented at a domestic level by national governments, through the formulation of climate policy. This implementation phase requires a diversity of groups, including businesses, rich and poor households, farmers, lobbyists, environmentalists and oil and mining companies, to work together to reduce emissions. As such, climate change mitigation is a prime example of a public good dilemma in which stakeholders are heterogeneous.

In this context, it is not immediately clear whether individuals will be able to reach consensus on a contribution norm. While communication has been found to be effective in facilitating cooperation when players are homogeneous, in a setting where players are heterogeneous,

communication might prove to be counterproductive, emphasising dissimilarities between players rather than fostering cooperation. Against this background, the second paper **“Cooperation and Climate Change: Can Communication Facilitate the Provision of Public Goods in Heterogeneous Settings?”** uses a public good game with a climate change framing to examine whether groups of heterogeneous individuals can meet a collective emission-reduction target through individual contributions. Subjects are able to communicate with one another in order to determine how to distribute the abatement burden. Players differ in terms of their marginal contributions to the public good (or, in terms of the framing, their marginal costs of abatement – with players either having high or low marginal abatement costs).

Players were urged to collectively contribute a minimum number of experimental currency units to the public good (again, in terms of the framing, this corresponded to meeting a national emission-reduction target). With the opportunity to communicate with group members, the proportion of groups that met the target increased from 35% to 50%. Furthermore, with the introduction of communication, average contributions of both player types increased significantly relative to the baseline treatments. Finally, the proportion of perfect co-operators of both player-types (players who contribute their full endowment to public good provision) also increased significantly with the introduction of communication.

However, the results also illustrate the problem with non-binding, piecemeal agreements. Free-riding was pervasive for both player-types in both the baseline and communication treatments; furthermore, the prevalence of free-riding increased significantly among players with a high marginal cost of abatement with the introduction of communication. As such, for both player types, cooperation was polarised between free-riding and perfect cooperation.

Given the climate change framing and context, subjects were not provided any information regarding the contribution behaviour of their group members: the rationale for this being that in a real-world setting, emission reduction totals are often estimates, there is a lag between mitigation activities and reporting by authorities and institutions and reporting of emission reduction activities are often voluntary (as is the case currently in South Africa). In this context it is likely that the non-binding nature of the group consensus coupled with the extreme anonymity of players (i.e. no feedback on contribution behaviour was provided) underpinned (i) the significant degree of free-riding, (ii) non-compliance with the group decision (during

the communication treatment) and (iii) the finding that contributions do not differ by player type. Ultimately, in terms of policy relevance in a climate change context, the implication is that anonymity needs to be stripped away, for example through mandatory reporting.

Furthermore, the results indicate that while stakeholder participation is important in promoting cooperation, there is always the risk that free-riders will engage in participatory processes on the formulation of climate policy, but then thwart efforts at the implementation phase by renegeing on an agreed-to mitigation obligation (the anonymity implicit in the design facilitated this). The implication is that punishment opportunities will likely play an important role in compelling cooperation.

Relatedly, players with high marginal abatement costs were found to free-ride significantly more than players with low abatement costs in the communication treatment. The implication is that the presence of heterogeneity – which is translated within the framework of the game as an inequality – provides individuals with a justification to renege on an agreement. In a climate change context, parties to the negotiations who view themselves as unfairly disadvantaged might be more prone to non-compliance. Participatory processes must thus take cognisance of the equity contexts within which the negotiations are happening (for example, equity is an important subtext in multilateral climate change negotiations).

(iii) Risk attitudes and choice of adaptation strategy in the context of uncertainty around the timing and severity of climate variability

While there is now broad consensus regarding the consequences of climate change, there is continued uncertainty around the timing and severity of climate change impacts (IPCC 2013). Accordingly, responding to the risks inherent in climate change (through adaptation) involves decision-making under uncertainty. With this in mind, any proposed adaptation policy with uncertain outcomes must take into account individuals' aversion to risk and the manner in which they make choices under conditions of uncertainty (Harrison *et al.* 2010).

In this context, the third paper of this thesis, “**Risk Attitudes and Adaptation: Experimental Evidence from a Flood-Prone Urban Informal Settlement in South Africa**”, characterises the risk attitudes and, more specifically, the relationship between risk attitudes and choice of

adaptation strategy, of a sample of individuals living in a particularly flood-prone urban informal settlement in Cape Town.

The observed risk attitudes of this low-income community and, more particularly, the relationship between risk attitudes and choice of adaptation strategy, are particularly interesting given that decisions around flood adaptation involve significant stakes. In particular, vulnerability to flood risk (and the financial loss and diminished wellbeing associated with flood damage to immovable property and possessions) are determined, in part, by choices regarding how to mitigate the risk of damage from flooding (in other words, choice of adaptation strategy). While there are a number of adaptation strategies that participants can implement in a bid to reduce their exposure to flood risk, there is significant variation in individuals' efforts to adapt.

The experiment reported in this paper replicates the design of Harrison and Rutström (2009) in which subjects are provided with 60 lottery tasks and, for each lottery task, choose between two lottery pairs. While the participants partake in either a gain, mixed or loss frame, endowments are used to equalise the payoffs across the frames

The results signal that adaptation strategies are broadly correlated with risk attitudes. Specifically, the results indicate that individuals that (i) do nothing, (ii) rely solely on plastic sheeting or (iii) raise their homes above ground, are less risk averse relative to individuals who (iv) slant their roofs to assist rainwater runoff.

This result implies that attempts by local authorities to encourage uptake of adaptation strategies must take into account risk attitudes (as opposed to assuming risk neutrality on the part of the decision maker). More specifically, given the level of variation in individual adaptation efforts, city officials might supplement ongoing education initiatives with proactive measures to incentivise even more risk-seeking individuals to engage with adaptation (for example, through the provision of a subsidy on building materials).

More generally, while risk preferences are often considered within very specific contexts – for example in applications to addiction, the result of this study indicates that attitudes toward risk impact on individual decision-making (and therefore welfare outcomes) within the wider

framework of our daily decision-making and in situations where relatively high financial stakes are involved.

(iv) Risk attitudes and adaptation when proposed adaptive strategies have uncertain outcomes

In addition to uncertainty around the timing and severity of climate change impacts (IPCC 2013), proposed adaptation strategies may also have uncertain outcomes. For example, within a developing country context, while the adoption of new farming practices to reduce vulnerability to climate change impacts has the potential to engender significant yield improvements, these practices are also potentially more risky relative to traditional agriculture. Mosley and Verschoor (2005) discuss the risk-induced poverty trap: poor individuals who are risk averse – and thus unwilling to invest in modern inputs because of these risks – will remain poor, while wealthier individuals who are in a position to insulate themselves from risk will benefit from technological innovations.

Against this background, the fourth and final paper, “**Risk Preferences, Technology Adoption and Insurance Uptake**” explores the potential for index-insurance to induce risk-averse individuals to opt into riskier and potentially more profitable farming practices.

To disentangle the effects of credit constraints from appetite for risk, we run a series of framed field experiments with a sample of South African subsistence farmers. In the first treatment, farmers choose between traditional agriculture (framed as traditional seeds) and investing in a new farming input that requires them to take out a loan (framed as high-yielding seeds with a loan). In a subsequent treatment, farmers make this decision again, but are provided with a third option of investing in high-yielding seeds with a loan and rainfall insurance. We also elicit farmers’ risk preferences using simple lottery tasks for real monetary prizes.

By omitting an insurance option from the initial treatment of the insurance games, we are able to examine whether the provision of the simulated insurance product induces risk-averse subjects to move from low risk, low return traditional agriculture to use of riskier but potentially more profitable high-yielding seeds. As such, we are able to assess whether the availability of insurance products, which reduce (but do not remove) the risks associated with the use of modern inputs, promotes technology diffusion and helps to break the poverty-trap

cycle by encouraging individuals (and particularly risk-averse individuals) to opt into riskier but potentially more profitable farming strategies.

Overall, the results of the experiment lend empirical weight to the poverty-trap argument. First, a high degree of risk aversion is evident among the sample. Secondly, irrespective of the level of production risk (the probability of good rainfall was varied at different probability levels), risk-averse individuals are more likely to opt into traditional agriculture (reflected as traditional seeds in the experiment) and are less likely to use modern farming inputs that require financing (high-yield varieties) irrespective of the availability of insurance.

The results confirm the long-held contention in the literature that pure risk preferences are a determinant in farmers' adoption decisions. However, they further indicate that index insurance is not a panacea when it comes to promoting technology diffusion.

The insurance product in this experiment was designed to reduce the loss experienced by the participants in the event of crop failure, but did not remove this loss entirely, and no doubt this impacted the results. This design reflects the idea that index insurance does not completely remove production and consumption risk, but rather reduces or minimises the risk. The laboratory experiment reflects the reality that index insurance does not remove all risk from the production process; specifically, even if a particular index insurance product completely removed the production risk associated with rainfall variability, arguably the most important source of production risk for farmers in developing countries, it would not pay out for crop damage derived from other factors (such as pests), known as basis risk (Barrett *et al.* 2007). Thus, in order to overcome risk aversion among poor individuals stuck in the poverty cycle and to facilitate the uptake of insurance products, basis risk and residual production risk not accounted for by the insurance product need to be targeted.

References

- Barrett, C., Barnett, M., Carter, S., Chantarat, J., Hansen, A., Mude, D., Osgood, J., Skees, C. 2007. Index Insurance for Climate Risk Management & Poverty Reduction. Adapted from IRI Technical Report 07-03, Working Paper - Poverty Traps and Climate Risk: Limitations and Opportunities of Index-Based Risk.
- Harrison, G., Rutström, E., 2009, "Expected Utility Theory and Prospect Theory: One Wedding and a Decent Funeral." *Experimental Economics*, 12:133-158.
- Harrison, G., Humphrey, S., Verschoor, A., 2010, "Choice under Uncertainty: Evidence from Ethiopia, India and Uganda." *The Economic Journal*, 120:80 – 104.
- IPCC, 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Mosley, P., Verschoor, A., 2005, "Risk Attitudes and the Vicious Circle of Poverty." *The European Journal of Development Research*, 17: 1, 59 — 88.