Climate Change Catastrophes and Insuring Decisions: A Study in the Presence of Ambiguity*

Sara le Roux†

20th February 2017

Abstract

There has been very little research to test whether ambiguity affects individuals' decisions to insure themselves against the catastrophic effects of climate change. This paper attempts to study how individuals respond to the availability of an insurance that would give them immunity to a climate change catastrophe. Moreover, if such an insurance is available to them, do they insure themselves sufficiently? Further, the study investigates the policy implications for insurance companies: does increased availability of information regarding the probability of the catastrophic event, lead to an increase in insurance subscriptions? Finally, policy implications for the State are investigated - Can State intervention ensure a better outcome?

Keywords: Climate change catastrophes; ambiguity; Choquet expected utility; strategic substitutes; nudge.

JEL Classification: C71, **C**91, **D**03, D81, Q54

*I would like to thank Dieter Balkenborg and Todd Kaplan for their permission to use FEELE lab and Tim Miller for his immense support in running the experiments. Many thanks are due to David Kelsey, Lawrence Choo, Lorenz Hartmann, Horst Zank, Briony Pulford, Israel Waichman and Dennis Dittrich for their comments and suggestions.

†**Address for Correspondence:** Sara le Roux, Department of Accounting, Finance & Economics, Oxford Brookes University, Wheatley Campus, Oxford OX33 1HX. E-mail: sle-roux@brookes.ac.uk

1 Introduction

The United Nations Framework Convention on Climate Change (1994), defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The vast majority of scientific work on climate change has come to the conclusion that its effect can already be seen in the form of a gradual but steady loss of sea ice, accelerated sea level rise and longer, more intense heat waves.

There exists a great deal of ambiguity surrounding climate change and the possibility that this climate change could at any point trigger a catastrophe, that would cause wide-scale damage. A climate change catastrophe can be viewed as a low-probability high-impact event. As such, the questions that need to be asked are: Given the ambiguity surrounding a catastrophic event taking place, are people sufficiently concerned in order to insure themselves against it? Moreover, if given the opportunity to protect themselves against such a catastrophe, do individuals sufficiently insure themselves?

There have been very few studies concerning individual behaviour regarding climate change. Most of the studies that have been conducted so far concentrate on whether communication, fairness and differences in endowment levels, affect how individuals coordinate to try and prevent climate change catastrophes. Milinski., Sommerfeld, Krambeck, Reed, and Marotzke (2008), study a collective-risk social dilemma game where players attempt to coordinate in order to prevent dangerous climate change.[1] It was found that more than half the subjects that participated in the study, failed to coordinate on a required threshold that would prevent climate change. Inability to communicate with group members was seen as a reason for the coordination failure. Tavoni, Dannenberg, Kallis, and Löschel (2011), study a similar game, where they attempt to embed an idea of inheritance or past wealth/debt among the players. Thus, "rich" players have a higher endowment than "poor" players. Players were allowed to communicate, so that they could *"pledge"* their intentional contributions.

[1] Subjects could observe the contribution levels of other players in their group.

The study found that the inequality introduced into the experimental setup made it harder for the players to coordinate, whereas the option of communicating improved the chances of coordination on the threshold.

This paper combines experimental and theoretical research, that studies the effects of ambiguity[2] on individuals' decisions to insure themselves against the catastrophic effects of climate change and provides recommendations for private insurers and government policy. The study investigates individuals' behaviour when taking part in a game similar to the public goods game. Unlike a regular public goods game, where the objective is to create a gain, the objective of this game is to avoid a loss due to a climate change catastrophe. Subjects are given an endowment and warned that they might be the victim of a climate change catastrophe. The catastrophe which occurs with some unknown probability, would result in them losing their endowment. They can safeguard themselves against such a loss, by contributing as a *group* towards insurance. The insurance is bought if a threshold is reached and safeguards the team as a whole in the event of a catastrophe taking place.

Each subject's contribution towards attaining the insurance may be viewed as a strategic substitute for the others'. In the presence of ambiguity, if a player thinks that the others in his group would not contribute towards the public good, it should prompt him to increase his own contribution, in order to buy the insurance and avoid catastrophic climate change. It is thus possible to get a theoretical prediction of subject behaviour, given that there is a clear worst case scenario – failing to buy the insurance and suffering a loss due to catastrophic climate change. If it is found that individuals fail to sufficiently safeguard themselves, it might be because they do not regard the climate change catastrophe as very likely to affect them - that is, they attach a very low probability to such an event happening. Another reason for this might be that they do not take into account the impact/magnitude that this catastrophe might have on them.

Storms, heat-waves, floods and droughts are becoming more frequent as a result of climate change. However, even with the increasing frequency of such high-impact events, it is found that people do

[2]When a decision-maker fails to assign a subjective probability to an event, ambiguity arises.

not sufficiently insure themselves. It has been seen in the past that individuals discount the future to a great extent, and as such fail to make sufficient provisions for the future. This raises an additional question. Should the State intervene if individuals fail to make adequate provision to insure themselves against the risk of a climate change catastrophe? Can a State intervention ensure a better outcome?

Moreover, it would be interesting to find out whether individuals are more likely to contribute towards the insurance if they are given some additional information regarding the impact/likelihood of a catastrophe. This would test whether insurance companies have the possibility of increasing the number of subscriptions, if people are better educated on the magnitude and devastation of these events.

2 Modelling Behaviour in the Presence of Ambiguity

The Ellsberg paradox is a well documented violation of the Subjective Expected Utility (SEU), Savage (1954). Subjects asked to choose between risky and ambiguous acts, tend to avoid the ambiguous act. Such behaviour is inconsistent with maximising expected utility with respect to a standard subjective probability distribution π. However these preferences are compatible with non-additive beliefs, introduced by Schmeidler (1989). Non-additive beliefs may be represented by a *capacity* or non-additive set function ν. Under **Choquet Expected Utility (CEU) (**Schmeidler (1989)), outcomes are evaluated by a weighted sum of utilities, but unlike EUT the weights used depend on the acts. The model preserves additivity in beliefs when there is conventional risk, while permitting non-additivity for ambiguous events. Within CEU individuals can be either optimistic or pessimistic in their outlook towards ambiguity. A pessimistic (resp. optimistic) outlook would over-estimate the likelihood of a bad (resp. good) outcome - inducing one to purchase a climate change catastrophe related insurance.

Neo-additive capacities were introduced by Chateauneuf, Eichberger, and Grant (2007). In this model the decision-maker has beliefs based on an additive probability distribution π. However (s)he lacks confidence in these beliefs hence they are ambiguous beliefs. The ambiguity is represented by the parameter δ. The individual's attitude to ambiguity is represented by the parameter α, with higher values of α corresponding to greater ambiguity-aversion. Consider a two-player game with a finite set of pure strategies S_i, such that s_i is the player's own strategy and S_{-i} denotes the set of possible strategy profiles for i's opponents. The payoff function of player i is denoted $u_i(s_i, s_{-i})$. The functional form of preferences may be represented as:

$$V_i\left(s_i; \pi_i, \alpha_i, \delta_i\right) = \delta_i \left(1 - \alpha_i\right) M_i\left(s_i\right) + \delta_i \alpha_i m_i\left(s_i\right) + \left(1 - \delta_i\right) \int u_i(s_i, s_{-i}) d\pi_i(s_{-i}), \tag{1}$$

where $M_i\left(s_i\right) = \max_{s_{-i} \in S_{-i}} u_i(s_i, s_{-i})$ and $m_i\left(s_i\right) = \min_{s_{-i} \in S_{-i}} u_i(s_i, s_{-i})$.[3] These preferences maximise a weighted average of the best payoff, the worst payoff and the expected payoff. They are a special case of CEU. They are also a special case of the α-MEU model, Marinacci (2002), which represents ambiguity by a set of probability distributions and ambiguity-attitude by the parameter α expressing the weight given to the minimum possible expected utility.

Intuitively, π can be thought to be the decision-maker's belief. However, he is not sure of this belief, hence it is an ambiguous belief. His confidence about it is modelled by $(1 - \delta_i)$, with $\delta_i = 1$ denoting complete ignorance and $\delta_i = 0$ denoting no ambiguity. His attitude to ambiguity is measured by α_i, with $\alpha_i = 1$ denoting pure pessimism and $\alpha_i = 0$ denoting pure optimism. If the decision-maker has $0 < \alpha_i < 1$, he is neither purely optimistic nor purely pessimistic (i.e., ambiguity-averse), but reacts to ambiguity in a partly pessimistic way by putting a greater weight on bad outcomes and in a partly optimistic way by putting a greater weight on good outcomes.

2.1 Modelling an Equilibrium under Ambiguity

In a Nash equilibrium, players are believed to behave in a manner that is consistent with the actual behaviour of their opponents. They perfectly anticipate the actions of their opponent and can thus

[3] Note that Chateauneuf, Eichberger, and Grant (2007) write a neo additive capacity in the form $\mu(E) = \delta\alpha + (1 - \delta)\pi(E)$. We have modified their definition to be consistent with the majority of the literature where α is the weight on the minimum expected utility.

provide a best response to it in the form of their own action. However, for non-additive beliefs, the Nash idea of having consistent beliefs regarding the opponent's action and thus being able to play a best response to these beliefs, needs to be modified. It is assumed that players choose pure strategies. In equilibrium, a player's beliefs about the pure strategies of his/her opponent must be best responses for that opponent, given the opponent's beliefs.

Unlike Nash equilibrium where a player can assign an additive probability distribution to his/her opponent's actions, ambiguous beliefs are represented by capacities. The support of a capacity is a player's belief of how the opponent will act. Formally, the support of a neo-additive capacity, $\nu(A) = \delta\alpha + (1-\delta)\pi(A)$, is defined by $\operatorname{supp}(\nu) = \operatorname{supp}(\pi)$. Thus the support of a neo-additive belief is equal to the support of its additive component.[4]

Definition 2.1 (Equilibrium under Ambiguity) *A pair of neo-additive capacities* (ν_1^*, ν_2^*) *is an Equilibrium Under Ambiguity (EUA), for* $i = 1, 2$ *and* $\operatorname{supp}(\nu_i^*) \subseteq R_{-i}(\nu_{-i}^*)$, *where* R_i *denotes the best-response correspondence of player* i, *given that his/her beliefs are represented by* ν_i *and is defined by:*

$$R_i(\nu_i) = R_i(\pi_i, \alpha_i, \delta_i) := \operatorname{argmax}_{s_i \in S_i} V_i(s_i; \pi_i, \alpha_i, \delta_i).$$

This definition of equilibrium is taken from Eichberger, Kelsey, and Schipper (2009), who adapt an earlier definition in Dow and Werlang (1994). These papers show that an EUA will exist for any given ambiguity-attitudes for the players. In games, one can determine π_i endogenously as the prediction of the players from the knowledge of the game structure and the preferences of others. In contrast, the degrees of optimism, α_i and ambiguity, δ_i, are treated as exogenous. In equilibrium, each player assigns a strictly positive likelihood to his/her opponent's best responses given the opponent's belief. However, each player lacks confidence in his/her likelihood assessment and responds in an optimistic way by over-weighting the best outcome, or in a pessimistic way by over-weighting the worst outcome.

Alternative approaches to equilibrium with ambiguity can be found in Klibanoff (1993) and Lo

[4] This definition is justified in Eichberger and Kelsey (2014).

(1996). They model players as having preferences which satisfy the axioms of maxmin expected utility (MMEU, Gilboa and Schmeidler (1989)). Players are allowed to have beliefs which are represented by sets of conventional probability distributions. As such, players can have mixed strategies that are chosen from these sets of probabilities. They model ambiguity aversion as a strict preference among players to randomise between strategies when they are indifferent between two pure strategies.

3 Experimental Model and Equilibrium

The experimental setup consists of *two* players[5], each given an endowment of $30ECU$, who play five rounds. In each round a player had the choice of contributing between $0-4$ ECU (they could make discrete contributions of $0, 1, 2, 3$ or $4ECU$) with the aim of getting a total contribution of $20ECU$, at the end of the five rounds. If at the end of the rounds, the players managed to reach the $20ECU$ threshold, they safeguarded themselves against the harmful impact of a climate change catastrophe. If they failed to reach the threshold, a climate change catastrophe may have occurred with some unknown probability, and the players lost all their money.[6]

Subjects were randomly matched into groups of two, and remained in the same group throughout the experiment. Subjects were not allowed to communicate with each other and no information about intermediate contribution levels was made available to subjects between rounds. As such, subjects would perceive ambiguity from two sources -

1) The interaction with other players - which results in ambiguity about the other subjects' choice of contribution levels.

2) Ambiguity caused because of the unknown probability with which climate change catastrophe may or may not occur.

[5]The design makes use of two players, since this makes it easier to calculate the theoretical equilibrium under ambiguity and the predicted contribution levels in the presence of ambiguity.

[6]For the experiments, the probability with which the climate change catastrophe struck was 0.8.

3.1 Nash equilibrium

The game has two symmetric pure strategy equilibria: One, where each player contributes a total of $10ECU$ over the five rounds (or $2ECU$/round), the safety threshold is reached and each player has a guaranteed final payoff of $20ECU$. Second, where each player contributes nothing each round, they fail to reach the threshold, and each has an expected payoff of $6ECU$.[7] It is clearly optimal then for each player to contribute $10ECU$ over the five decision rounds, which makes this the more efficient equilibrium strategy.

3.2 Equilibrium under Ambiguity

Consider Player 1. Suppose she holds beliefs which are represented by a neo-additive capacity: $v(A|\alpha, \delta, \pi) = \alpha\delta + (1-\delta)\pi(A)$. Given these beliefs Player 1's Choquet expected utility (CEU) from the choice of n_1 is:

$$V_1(n_1; \alpha, \delta, \pi) = \delta\left[\alpha \text{ max } u_1(n_1, n_2) + (1-\alpha) \text{ min } u_1(n_1, n_2)\right] + (1-\delta)\sum u_1(n_1, n_2) \cdot \pi(n_2).$$

The inefficient Nash, where players contribute $0ECU$ per round and fail to reach the safety threshold, is ignored.

If Player 1 contributes $2ECU$ per round: The maximum payoff she earns if the threshold is reached, is $20ECU$. Else, if the threshold is not reached and the climate change catastrophe occurs, she earns $0ECU$. Let the probability with which Player 2 contributes $2ECU$ per round be $\tilde{\pi}_2$. The CEU of Player 1 from contributing $2ECU$ per round can be computed as:

$$\begin{aligned} \tilde{V}_1 &= \delta\left[\alpha \cdot 20 + (1-\alpha) \cdot 0\right] + (1-\delta)(20 \cdot \tilde{\pi}_2) \\ &= 20\delta\alpha + 20(1-\delta)\tilde{\pi}_2. \end{aligned}$$

If Player 1 contributes $4ECU$ per round: The threshold is always reached. Player 1, thus has a

[7] The expected payoff when the threshold is not reached $= (0.8 * 0) + (0.2 * 30) = 6ECU$.

secure payoff of $10ECU$. The CEU of Player 1 from contributing $4ECU$ per round is thus: $\hat{V}_1 = 10$.

Player 1 will prefer to contribute $4ECU$ per round if:

$$\begin{aligned} \hat{V}_1 &> \tilde{V}_1, \\ 10 &> 20\delta\alpha + 20(1-\delta)\tilde{\pi}_2 \\ \frac{1}{2} &> \delta\alpha + (1-\delta)\tilde{\pi}_2. \end{aligned}$$

Based on Player 1's belief of $\tilde{\pi}_2$, $\hat{V}_1$ is strictly preferred if:

$$\delta(1-\alpha) > \frac{1}{2} > \delta\alpha.$$

Thus, if Player 1 is sufficiently ambiguous about Player 2's contributions, she should contribute $4ECU$ per round, in order to ensure that the threshold is reached. The EUA for Player 2 is symmetric to that of Player 1. He should also contribute $4ECU$ per round if he is ambiguous about the safety threshold being reached.

The testable hypothesis is that though Nash equilibrium predicts subjects should contribute $2ECU$ per round or $10ECU$ in total, EUA suggests that subjects who are ambiguity-averse would contribute more $(3/4ECU)$ per round in order to ensure the safety threshold is reached.

4 Experimental Design

The experiments were coded using z-Tree software (Fischbacher (2007)). Four treatments were employed as under -

Treatment I - This is the base treatment, where subjects were informed that the catastrophe will occur with an unknown probability and they must coordinate with the team-member (one other person), in order to buy the climate change insurance.

All subsequent treatments were variations of Treatment I as below:

Treatment II - In this treatment, subjects were informed "In the past few periods, climate change catastrophes are known to have struck at least 80% of the time." Thus, subjects are given additional information about the probability with which catastrophes have occurred in the past. It is important to note here that the probability with which the catastrophic event takes place in the current period is an independent event, whose probability is still ambiguous. The aim of this treatment is to check whether educating/informing subjects about the frequency of the catastrophe in the past leads to an increase in the insurance contributions.

Treatment III - In this treatment, subjects were informed that they "have been assigned to a team, where a computer is the other player. The computer you are teamed with, has been programmed to contribute $2ECU$/round. Do not expect it to deviate from this strategy." Thus, this treatment removes the strategic uncertainty involved in coordinating with another player. This treatment strictly captures the ambiguity-averse reaction to the climate change event. If subjects are not ambiguity-averse to the climate event, they should contribute $0ECU$.

Treatment IV - In this treatment, subjects were informed that "The government has taken into account the grave losses that might occur as a result of a climate change catastrophe. As such, with your best interests at heart, all players are pre-assigned to a $2ECU$/round level of contribution towards the insurance. If you are unhappy with this pre-assigned contribution level, you can change your contribution, but will need to confirm this decision by answering a simple mathematics question." Thus, all subjects are "pre-assigned" to a contribution level. If subjects are dissatisfied with this automatic assignment, they needed to take conscious (and concrete) steps to opt off it. As such, subjects could not opt off as a result of a "tremble". The pre-assigned contribution level, is the contribution level predicted by the Nash equilibrium. The aim of choosing the solution predicted by the Nash equilibrium was to evaluate how people react in a situation where a Nash equilibrium pre-existed (i.e., do people deviate from a pre-existing Nash equilibrium?).

The experimental sessions were conducted at the Finance and Economics Experimental Laboratory in Exeter (FEELE), UK between October 2015 and May 2016. In total 719 subjects took part in the experiments, 319 of whom were male and the remaining 400 were female. The breakdown of subjects between treatments were as follows: Treatment I - 180 subjects, Treatment II - 192 subjects, Treatment III - 153 subjects and Treatment IV - 194 subjects. Each session lasted a maximum of 45 minutes including payment.

Subjects first read through a short, comprehensive set of instructions at their own pace.[8] The subjects were then asked to fill out practice questions to check that they understood the games correctly. Subjects could not proceed to the main experiment until they had correctly answered the practice questions. As such, if subjects were unable to answer a question correctly, they were assisted and their doubt/query resolved before they proceeded to take part in the main experiment. Subjects were randomly assigned to groups of two (except Treatment III, where they were paired with the computer), and remained in the same group for the rest of the experiment.

The experiment was "framed", explicitly mentioning a climate change catastrophe, and the provision threshold of $20ECU$ was common knowledge among the participants. In each round, subjects had to make a decision about how much to contribute (between $0 - 4ECU$) towards the group insurance. Each subject could only select one option per round. In Treatment IV, subjects were pre-assigned to a contribution of $2ECU$ per round, and had to solve a simple mathematics question correctly in order to deviate from the pre-assigned selection. Participants were not reminded about their own previous cumulative contributions.

Subjects could not communicate with each other during the experiment. Moreover, they received no information about their team member's contribution decisions between rounds - therefore, there was no opportunity to update one's beliefs.

Once subjects had made all decisions, the result screen informed subjects about how much the group contribution towards the insurance had been and whether the insurance had been purchased. There was no reimbursement of contributions, if the threshold was not reached or if surplus contributions were made to the insurance. The computer used a random algorithm to simulate whether or not the climate change catastrophe had occurred, and calculated the final payoff in ECU and

[8] The experimental protocols are available here: http://saraleroux.weebly.com/experimental-protocols.html

GBP, for each subject. Subjects were paid a show-up fee of £3, together with their earnings, where $5ECU = £1$.[9] Average payoffs per treatments were as follows: Treatment I - £5.50, Treatment II - £6, Treatment III - £6.40 and Treatment IV - £5.50.[10]

5 Data Analysis and Discussion

Observed subject behaviour in the experiments, on the whole, suggested that subjects were indeed concerned about the losses that could be caused by a climate change catastrophe. Table 1, shows the number of groups that successfully reached the required threshold and safeguarded themselves against the climate change catastrophe. Binomial tests were run to ascertain whether the number of groups reaching the threshold in each treatment was significantly more than the number of groups that failed to reach the threshold. Table 2 shows that null was rejected at a 1% significance level overall and for Treatments I, II and III, and at a 5% significance level for Treatment IV.

Table 1: Success in buying the Climate Change Insurance

	T I	*T II*	*T III*	*T IV*
No. of groups participating	90	96	153	97
No. of groups reaching threshold	60	76	124	57
No. of groups not reaching threshold	30	20	29	40
% of successful groups	66.67%	79.17%	81.05%	58.76%

Table 2: Binomial Test Results

Null Hypothesis (H_0):	$prob$(threshold reached) = $prob$(threshold not reached)
Alt. Hypothesis (H_1):	$prob$(threshold reached) > $prob$(threshold not reached)
Treatment I	3.1623***
Treatment II	5.7155***
Treatment III	7.6803***
Treatment IV	1.7261**
Overall	9.4825***
*, **, *** indicate significance levels of 10%, 5% and 1% respectively.	

Only 19 (2.64%) out of the total 719 subjects that took part in the experiments contributed nothing towards buying the insurance (i.e., $0ECU$ in each round). It was found that there were only

[9] Participants' show-up fee was not affected by the climate change catastrophe.
[10] Payoffs were round up to the nearest $20p$, for the purpose of payment.

Table 3: Individual Contribution Levels

	Group A		Group B		Group C	
Treatment I	38	21.11%	94	52.22%	48	26.67%
Treatment II	24	12.50%	105	54.69%	63	32.81%
Treatment III	29	18.95%	97	63.40%	27	17.65%
Treatment IV	53	27.32%	96	49.48%	45	23.20%
Overall	144	20.03%	392	54.52%	183	25.45%

2 (0.28%) subjects who were ambiguity-averse enough to contribute $4ECU$ each round.[11] Table 3 classifies subjects according to their total contribution towards purchasing the insurance. Subjects contributing less than $10ECU$ fall in Group A, subjects contributing exactly $10ECU$ (or the contribution level predicted by the efficient Nash) fall in Group B, and subjects contributing more than $10ECU$ (or those conforming with the Equilibrium under Ambiguity prediction) fall in Group C.

In Treatment I (the base treatment), two-thirds of the groups (60 groups) successfully purchased the insurance. This shows us that subjects are indeed concerned about climate change catastrophes and their impact. When given the opportunity to insure themselves, subjects tend to do so. From Table 3, one can note that approximately 21% of subjects (Group A) have a tendency to free-ride; about half of them (Group B) attempted to coordinate in order to achieve the more efficient Nash, and about 26% (Group C) contributed more towards the insurance, as predicted by the EUA. It is clear that a majority of subjects conform to the efficient Nash prediction, however, a significant number of subjects contribute more than predicted by Nash. Another factor that could be affecting the decision of subjects that fall in Group C (in Treatment I), may be weak altruism (Wilson (1990)). As such, subjects willingly bear the burden of purchasing the insurance on their own, in order to safeguard the team as a whole.

In Treatment II, subjects were given more information regarding the frequency with which the catastrophe had occurred in the past. Subjects were found to take this additional information on board, and this results in an increase in the number of groups that successfully purchase the insurance to 79.17% (76 groups). A Fisher exact test[12] shows that there is a significant increase in

[11] Only two subjects contributed $4ECU$ per round: one played in Treatment I and the other in Treatment IV.

[12] (H_0 :The proportion of groups buying insurance in $T\ I$ and $T\ II$ are indentical, H_1 :The proportion of groups buying insurance in $T\ I$ and $T\ II$ are not identical)

the number of groups purchasing the insurance, when compared to the base treatment ($P = 0.069$). As such, if individuals are given more information about the growing frequency of climate change catastrophes, they update their beliefs and successfully insure themselves. The policy implications of this for insurance companies is that, if they provide better information to customers about the damage caused by climate change catastrophes, their insurance subscriptions would increase.

In Treatment III, the strategic uncertainty of coordinating with another player was removed. Subjects were paired with a computer, programmed to contribute $2ECU$. From the data, it can be seen that 81.05% (124 subjects) successfully reached the required threshold - i.e., when strategic uncertainty was removed, the number of subjects purchasing the insurance increased. When compared to the base treatment, a Fisher exact test[13] shows that there is a significant difference in the number of subjects purchasing the insurance in Treatment III ($P = 0.014$). In this treatment, if subjects are not concerned about the climate change catastrophe, they should contribute $0ECU$. The data gathered in the experiments, finds that 6 subjects contributed $0ECU$ towards the insurance, in this treatment. Thus a small minority (3.92%) of subjects did not find the catastrophe a matter of concern. In this treatment, it is inefficient to contribute both more and less than $10ECU$, since the computer is guaranteed to contribute the remaining. There were 27 subjects who contributed more than $10ECU$, and 23 subjects who made a positive contribution (i.e., greater than $0ECU$) but not enough to reach the threshold.

In Treatment IV, subjects were pre-assigned to a contribution level of $2ECU$ by a "benevolent" Government. It was found that the number of groups successfully purchasing the insurance (58.76%, i.e., 57 groups) was lower than in the base treatment. It is very interesting to note that Government intervention or the "nudge" seems to have backfired - i.e., subjects exerted an effort to opt-off the pre-assigned contribution level. A Fisher exact test[14] finds no difference between Treatments I and IV ($P = 0.292$), reflecting that the "nudge" was not successful in affecting people's behaviour or that it

[13] (H_0 :The proportion of groups buying insurance in $T\ I$ and $T\ III$ are indentical, H_1 :The proportion of groups buying insurance in $T\ I$ and $T\ III$ are not identical)

[14] (H_0 :The proportion of groups buying insurance in $T\ I$ and $T\ IV$ are indentical, H_1 :The proportion of groups buying insurance in $T\ I$ and $T\ IV$ are not identical)

may have even caused a "rebellious" behaviour on the part of subjects. This is termed a "*boomerang effect*" in psychology, where an attempt to persuade a subject, results in the unintended consequence of him/her adopting an opposing position instead (Brehm and Brehm (1981)). In particular, 53 (27%) subjects exerted the extra effort required to reduce their contribution level. Interestingly, 45 (23%) subjects exerted the extra effort required in order to *increase* their contribution levels. These subjects display that they are willingly to contribute more than the standard State-required contribution level in order to avoid ambiguous losses. About 50% of the subjects (96 subjects) remained at the "State-determined" pre-assigned contribution level.

The standard Ellsberg (1961) urn question was posed to the subjects, in order to determine their ambiguity-attitude.[15] Dummy variables were defined for the various treatments ($Treatment\ I$, $Treatment\ II$, etc.) and to capture subjects' ambiguity-attitude ($Ambiguity-Averse/Ambiguity-Seeking$). A probit regression was run to ascertain what factors increased the likelihood of the insurance being bought.

A probit regression of "*Bought*" on the various treatment and ambiguity-attitude dummies has a chi-square ratio of 36.55 with a p-value of 0.0000, which shows that our model as a whole is statistically significant.[16] Regression results are seen below.[17]

$$\begin{aligned} Bought &= 0.226 + 0.379(Treatment\ II) + 0.431(Treatment\ III) - 0.219(Treatment\ IV) \\ &\quad +0.294(Amb - Averse) \end{aligned}$$

[15]The question posed to the subjects was:
An urn contains 90 balls, of which 30 are labelled X. The remainder are labelled either Y or Z. Which of the following options do you prefer?
a) Payoff of 100 if a ball labelled X is drawn.
b) Payoff of 100 if a ball labelled Y is drawn.
Ambiguity-averse subjects should choose to bet on balls labelled X, as their quantity is known. Ambiguity-seeking subjects would choose to bet on balls labelled Y, whose quantity is unknown. (The question was not incentivised.)

[16]The dummy for Treatment I and Ambiguity-seeking attitude were dropped from the probit regression, in order to avoid the problem of collinearity. Dummies for mathematical ability, risk-attitude and gender were found to be insignificant, and were thus dropped from the final regression.

[17]The coefficients from a probit regression do not have the same interpretation as coefficients from an Ordinary Least Squares regression. From the probit results, we can interpret that when in Treatment II: the z-score increases by 0.38, in Treatment III: the z-score increases by 0.43, in Treatment IV: the z-score decreases by 0.219, when compared to the base which is Treatment I. Moreover, if a subject is ambiguity-averse (s)he is more likely to purchase the insurance.

There was no significant difference between Treatments I and IV. However, for Treatments II and III, subjects purchased the insurance significantly more often than in Treatment I. Moreover, if a subject displays ambiguity in the classic Ellsberg urn situation, they are significantly more likely to purchase the insurance.

6 Conclusion

It was found that on the whole, a majority of subjects do reach the threshold required to insure themselves against the climate change catastrophe. Removing the strategic uncertainty of contribution towards the insurance (Treatment III) and increasing the information about the frequency of climate change catastrophes that have occurred in the past (Treatment II), leads to a significant increase in insurance subscriptions. Interestingly, a State intervention or a "nudge" does not have the intended effects. State intervention was in fact counter-productive, and may have resulted in a fall in subscriptions.

A majority of the subjects' behaviour was consistent with Nash predictions, however, a sizable minority did display behaviour consistent with an ambiguity-averse attitude. It is important to note that it is easier to coordinate on the Nash equilibrium, when the group consists of two people. Increasing the group size beyond two, might result in failures in coordination and/or increase in contributions fuelled by ambiguity-averse behaviour (since strategic ambiguity can be seen to increase with group-size).

Overall, it was found that individuals are increasingly concerned about climate change and the resultant impact it is having on our every day lives. As such, there may be scope for insurance companies to offer insurances tailored specifically to cover climate-change related catastrophes. An insurance of this type would require a widespread up-take, for it to be feasible from the insurance companies' point of view. Unless individuals perceived to live in "high-risk" areas, are cross-insured by individuals living in "lower-risk" areas, insurance companies would find that all their customers were "lemons" and would quickly go out of business.

In future investigations, it might be interesting to ascertain whether subjects who failed to reach the threshold and lost their endowment as a result of the catastrophe "occurring", behave differently if they are asked to play the game again. This would be an extension of Treatment II, since subjects will have experienced first-hand the damage caused by failing to secure the insurance. In reality, insurance premiums would increase to reflect the growing frequency of the catastrophe. As such, it would be interesting to see whether subjects are willing to pay *more* to buy an insurance, which they had failed to purchase previously at a lower price. The key idea here is to investigate whether experiencing a low-probability high-impact event can change the ambiguity-attitude of a subject.

Climate change and its allied effects are becoming inevitable, as such, greater measures need to be put in place to safeguard individuals' interests. In this study, indirect state interventions or nudges, were found to be ineffective in the climate change context. As such, further investigations may be needed to ascertain more direct mechanisms that would ensure a better outcome.

References

Brehm, S., and J. Brehm (1981): "Psychological reactance: a theory of freedom and control," *New York: Academic Press.*

Chateauneuf, A., J. Eichberger, and S. Grant (2007): "Choice under Uncertainty with the Best and Worst in Mind: NEO-Additive Capacities," *Journal of Economic Theory*, 137, 538–567.

Dow, J., and S. R. C. Werlang (1994): "Nash Equilibrium under Uncertainty: Breaking Down Backward Induction," *Journal of Economic Theory*, 64, 305–324.

Eichberger, J., and D. Kelsey (2014): "Optimism and Pessimism in Games," *International Economic Review*, 55, 483–505.

Eichberger, J., D. Kelsey, and B. Schipper (2009): "Ambiguity and Social Interaction," *Oxford Economic Papers*, 61, 355–379.

Ellsberg, D. (1961): "Risk, Ambiguity and the Savage Axioms," *Quarterly Journal of Economics*, 75, 643–669.

Fischbacher, U. (2007): "z-Tree: Zurich toolbox for ready-made economic experiments," *Experimental Economics*, 10(2), 171–178.

Gilboa, I., and D. Schmeidler (1989): "Maxmin Expected Utility with a Non-Unique Prior," *Journal of Mathematical Economics*, 18, 141–153.

Klibanoff, P. (1993): "Uncertainty, Decision and Normal Form Games," *working paper, Northwestern University.*

Lo, K. C. (1996): "Equilibrium in Beliefs under Uncertainty," *Journal of Economic Theory*, 71, 443–484.

Marinacci, M. (2002): "Probabilistic Sophistication and Multiple Priors," *Econometrica*, 70, 755–764.

Milinski., M., R. D. Sommerfeld, H.-J. Krambeck, F. A. Reed, and J. Marotzke (2008): "The collective-risk social dilemma and the prevention of simulated dangerous climate change," *PNAS*, 105 (7), 2291–2294.

Savage, L. J. (1954): *Foundations of Statistics.* Wiley, New York.

Schmeidler, D. (1989): "Subjective Probability and Expected Utility without Additivity," *Econometrica*, 57, 571–587.

Tavoni, A., A. Dannenberg, G. Kallis, and A. Löschel (2011): "Inequality, communication and the avoidance of disastrous climate change," *Centre for Climate Change Economics and Policy and Grantham Research Institute on Climate Change and the Environment working papers.*

Wilson, D. S. (1990): "Weak Altruism, Strong Group Selection," *Oikos*, 59(1), 135–40.