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

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Abstract

This paper attempts to study how individuals respond to the availability of an insurance that would safeguard their interests if a climate change catastrophe occurred. If such an insurance is available to them, do individuals insure themselves sufficiently? Further, the study investigates if information regarding the past occurrence of the catastrophic event leads to an increase in insurance subscriptions and/or the emergence of a lemons market. Finally, policy implications are investigated - Can an indirect intervention in the form of a "nudge" ensure a better outcome?

Keywords: Climate change catastrophes; insurance; public goods; uncertainty; Choquet expected utility; strategic substitutes; lemons market; nudge.

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

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1 Introduction

There exists a great deal of uncertainty surrounding the effects of climate change and the possibility that this climate change could at any point trigger a weather-related catastrophe. A climate change catastrophe can be viewed as a low-probability high-impact event that causes wide-scale damage. Extreme weather-related events such as hurricanes, wildfires, storms and flooding are increasingly being attributed to climate change and are becoming a public policy concern. Consider the case of Dawlish, a small village in the county of Devon, UK. In February 2014, parts of southern Britain were hit by a severe storm, that led to the collapse of a section of the sea wall in Dawlish and left the railway to Cornwall suspended in mid-air. The storm also affected residents in nearby Somerset, who were evacuated amid fears that flood defences could be overwhelmed. The government at the time pledged an extra £100m for flood works and set up a "Flood Grants Scheme" to provide grants for homeowners in England affected in the future. Similar levels of damage have been caused more recently by Hurricanes Harvey, Irma and Maria, with liabilities amounting to several billions of dollars in aid and restoration work.

The aid received by victims of these events though very welcome, seldom covers their liabilities completely. Given the uncertainty surrounding a catastrophic event taking place, it would be interesting to investigate whether people are sufficiently concerned in order to insure themselves against extreme weather events. Moreover, if given the opportunity to protect themselves against such a catastrophe, do individuals insure themselves?

This paper combines experimental and theoretical research to study the effect of uncertainty on individuals' contribution decisions towards a climate change "insurance", that would mitigate and/or pool and transfer the risks of climate change related events. Consider a small community that must build sea/river defences to protect itself from flooding. The community begins an initiative to gather funds to build a dyke, which will only be built if a certain threshold of contributions is reached. The dyke, if built, protects everyone equally irrespective of personal contributions. A threshold public goods game thus arises, where a minimum amount of contributions needs to be raised for provision to occur. In this example, the climate change "insurance" contributions are being used to adapt and mitigate the effects of a climate change catastrophe *directly*.

More indirectly, contributing to the insurance could be seen as a method of pooling and transfer of risks, such that if a catastrophe occurred, any losses suffered would be financially compensated. A contribution threshold would need to be reached in order to make it viable for an insurance company to provide cover. With this in mind, a *threshold* public goods game is used to model individuals' contribution decisions towards the group insurance. If the threshold contribution level is reached, the insurance is purchased and would financially compensate victims against losses suffered due to an extreme weather event.

If it is found that individuals fail to safeguard themselves (i.e., the threshold is not reached), it might indicate that a very low probability is attached to such an event. It might be that giving subjects information about the increasing frequency of such events, could help in improving contributions. This would test whether better access to information results in increased subscriptions. Further, it would also provide a check against the emergence of a "lemons market"[1]. Private insurers would be hesitant to provide insurance if only high-risk individuals subscribed to their insurance, which would result in market failure due to a missing market[2].

In the event of a missing market, governments may decide that the provision of insurance cover has many elements of a public good. State involvement in providing flood insurance to residential and non-residential properties is already common, with many countries already putting public-private or government-funded schemes in place. Further, it has been documented (See Winston & Woodbury (1991)) that individuals discount the future to a great extent and fail to make sufficient provisions for themselves. It would be interesting to investigate whether the State should intervene if individuals fail to insure themselves against the risk of a climate change catastrophe. Could an indirect intervention or "nudge" that changes the default contribution status overcome behavioural biases that result in

[1] The term is attributed to Akerlof (1970), who established that in the presence of assymetric information in a market, the quality of goods traded on the market deteriorated, leaving only "lemons" or the bad kind of buyer/seller behind in the market.

[2] A missing market is a situation that emerges when a competitive market allowing the exchange of a commodity would be Pareto-efficient, but no such market exists.

people failing to optimally insure themselves?

The study finds that subjects respond in an averse manner to the uncertainty surrounding the climate event, with 67% of subjects successfully purchasing the climate change insurance. When subjects have more information about the growing frequency of such events, 79% successfully insure themselves. This may give rise to a "lemons" problem, with only high-risk individuals/regions subscribing towards climate change insurance and suggests that government intervention may be required to ensure market failures do not arise. When the strategic uncertainty of coordinating with another person is removed, 81% of subjects are successful in buying the insurance. An indirect intervention in the form of a nudge was unsuccessful, with only 58% of subjects successfully buying the insurance.

2 Related Literature

There is a growing body of economic studies on climate change. Stern (2006) is one of the most significant studies that analyses the market failures caused by climate change and proposes a range of mechanisms including environmental taxes to minimise the economic and social disruptions caused by climate change. McKibbin & Wilcoxen (2002) consider the role of economics in climate change policy and suggest the use of a hybrid model that incorporates the best features of tradable permits and emissions taxes.

A number of studies have been conducted that analyse permit trading in the context of climate change (see Bohm & Carlen (2002), Cramtom & Kerr (2002), Altamirano-Cabrera & Finus (2006), Wråke *et al.* (2008)), while the case for taxing green house gas emissions is considered by Metcalf (2007), Avi-Yonah & Uhlmann (2009), Gerlagh *et al.* (2009) among others. There have also been studies that consider the behavioral economics of climate change, in particular, the implications of prospect theory, the equity premium puzzle and time inconsistent preferences in the choice of discount rate used in climate change cost assessments (for a detailed analysis see Brekke & Johansson-Stenman (2008)).

Further, there have been studies that investigate individual behaviour regarding climate change to determine whether communication (Milinski *et al.* (2008)), fairness and differences in endowment levels (Tavoni *et al.* (2011)), affect how individuals coordinate to try and prevent climate change catastrophes. Barrett & Dannenberg (2012) investigate whether uncertainty about climate change affects international cooperation, by modelling climate negotiations as a coordination game. Dannenberg *et al.* (2015) analyse whether uncertainty regarding the level of the threshold affects collective action in threshold public goods games.

Unlike the Dannenberg *et al.* (2015) study, subjects in the current study do not face uncertainty regarding the level of the threshold. Subjects are aware of the threshold required to purchase the insurance but face uncertainty because of the unknown probability with which a climate change catastrophe may or may not occur (exogenous uncertainty) and uncertainty about the other subject's choice of contribution levels (endogenous uncertainty).

Subjects' contribution decisions are modelled by a threshold public goods game. For an extensive survey of the literature on public goods, see Ledyard (1995). Uncertainty in the standard public goods model has been previously studied in Eichberger & Kelsey (2002) and Bailey *et al.* (2005). Weakest-link/best-shot versions of the public good game with strategic uncertainty have been studied by Kelsey & le Roux (2017). This study adds to the existing literature by analysing the effect of uncertainty in threshold public goods games.

3 Experimental Model and Equilibrium

Individuals' contribution decisions are modelled using a threshold public goods game. Subjects who take part in the game are given an endowment and informed that they might be the victim of a climate change catastrophe. The catastrophe which occurs with some unknown probability,[3] would result in them losing their endowment. Subjects can safeguard themselves against such a loss, by contributing as a *team* towards insurance. The insurance is bought if the threshold is reached and

[3] The probability distribution was pre-determined but the realisation outcome was randomly determined by z-Tree.

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' contributions. In the presence of uncertainty, 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 (Kelsey & le Roux (2017)). It is thus possible to get a theoretical prediction of subject behaviour, given that there is a clear worst case scenario – failure to buy the insurance and a loss due to catastrophic climate change.

In line with Eichberger & Kelsey (2011), the introduction of uncertainty helps to better predict behavior in the games considered than Nash equilibrium. A theoretical equilibrium under uncertainty can be calculated such that a player optimises his/her contribution, based on his/her belief about *one* other opponent's contribution. Alternatively, a player may optimise against a number of opponents whose contributions are taken as a group, such that the player then optimises his/her contribution based on the belief about the group's total contribution.

For simplicity, the experimental setup in the current study makes use of *two* players, each given an endowment of 30 Experimental Currency Units (ECU), who play five rounds.[4] In each round a player could contribute between $0 - 4$ ECU (discrete contributions) with the aim of getting a total joint 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, the players would lose their endowment if a climate change catastrophe occurred.

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 between rounds. As such, subjects would perceive uncertainty from two sources:

1) Uncertainty arising due to the unknown probability with which climate change catastrophe

[4] The problem may be viewed as a one-shot game but was planned to consist of five rounds to reflect that insurance premiums are paid over a few periods rather than as a one-time lump sum payment.

may or may not occur (exogenous uncertainty).

2) Strategic uncertainty arising from the interaction with other players, i.e., uncertainty about the other subject's choice of contribution levels (endogenous uncertainty).

3.1 Nash equilibrium

In a Nash equilibrium, players are believed to behave in a manner that is consistent with the actual behaviour of their opponents. They predict the actions of their opponent with perfect accuracy and can thus provide a best response to it in the form of their own action.

The probability with which the catastrophe would occur was determined by a random generator on z-Tree (Fischbacher (2007)), such that the catastrophe occurred with a maximum probability of 80%. The Nash equilibria for the game are discussed below.

Proposition 3.1 *The threshold public goods game has two symmetric pure strategy Nash equilibria:*

1. *Where each player contributes nothing each round and they fail to reach the threshold;*

2. *Where each player contributes a total of* $10ECU$ *over the five rounds and the safety threshold is reached.*

Given the (maximum) probability with which the catastrophe may occur, the expected payoff when no contributions are made towards the insurance is: $(0.8 * 0) + (0.2 * 30) = 6ECU$, i.e., 80% of the time the catastrophe occurs and the subjects lose their entire endowment, while 20% of the time the catastrophe does not occur and the subjects keep their initial endowment. When each player contributes a total of $10ECU$ over the five rounds, the safety threshold is reached and each player has a guaranteed final payoff of $20ECU$.

For lower probabilities of a catastrophe ($\pi < \frac{1}{3}$), the strategy combination in which everyone contributes $10ECU$ is no longer a Nash equilibrium, but given the probability with which the random generator may determine that the catastrophe occurs, it is optimal for each player to contribute $10ECU$ over the five decision rounds, which makes this the more efficient symmetric equilibrium strategy.

Proposition 3.2 *The threshold public goods game has multiple asymmetric Nash equilibria, where any combination of contributions from the two players which is equal to the threshold level of* $20ECU$ *is a Nash equilibrium.*

In essence, there is no difference between the efficient symmetric equilibrium and the asymmetric equilibria. However, both contributing more and contributing less than necessary to reach the threshold, is inefficient.

3.2 Equilibrium under Uncertainty

In the presence of uncertainty, the Nash equilibrium concept of accurately predicting the opponent's behaviour is no longer valid and needs to be modified. Unlike Nash equilibrium where a player can assign an additive probability distribution to his opponent's actions, in the presence of uncertainty, the beliefs of a player are represented by a neo-additive capacities. Neo-additive capacities were introduced by Chateauneuf *et al.* (2007), as a way of capturing non-additive probabilities. In this model the decision-maker has beliefs based on an additive probability distribution π. However the decision-maker lacks confidence in these beliefs, which are thus uncertain beliefs. The endogenous uncertainty the decision-maker faces in a given situation is represented by the parameter δ. The individual's attitude to exogenous uncertainty is represented by the parameter α, with higher values of α corresponding to the belief that the catastrophe is more likely to take place.

Schmeidler (1989) proposed a theory called Choquet Expected Utility (CEU), where outcomes are evaluated by a weighted sum of utilities, but unlike Expected Utility Theory the weights used depend on the acts. Applying the model of decision-making under uncertainty to the two-player game being studied in this paper: If x_i is the action chosen by Player 1 from the set that contains all her strategies: X_i; and x_{-i} denotes the action chosen by her opponent (Player 2) from the set that contains all his strategies: X_{-i}, the payoff function measuring the CEU of Player 1 may be represented as:[5]

$$V_i(x_i; \alpha_i, \delta_i, \pi_i) = \delta_i \left[\alpha_i \min_{x_{-i} \in X_{-i}} u_i(x_i, x_{-i}) + (1-\alpha_i) \max_{x_{-i} \in X_{-i}} u_i(x_i, x_{-i})\right] + (1-\delta_i) E_{\pi_i} u_i(x_i, x_{-i}),$$

where $\mathrm{E}_{\pi_i} u_i(x_i, x_{-i})$ is a conventional expectation taken with respect to the additive probability distribution π on X_{-i}.

The CEU of a player maximises a weighted average of the best payoff, the worst payoff and the expected payoff. Intuitively, π can be thought to be the decision-maker's belief about the opponent's action. However, this is an uncertain belief. Her reaction to this endogenous uncertainty is modelled by $(1-\delta_i)$, with $\delta_i = 1$ denoting complete ignorance about the opponent's behaviour (or contribution level) and $\delta_i = 0$ denoting complete certainty about the opponent's behaviour. Her attitude to exogenous uncertainty (regarding the climate event) is measured by α_i, with $\alpha_i = 1$ denoting pure pessimism with respect to the climate change event taking place and $\alpha_i = 0$ denoting pure optimism about the chances of the catastrophic event taking place. If the decision-maker has $0 < \alpha_i < 1$, she is neither purely optimistic nor purely pessimistic (i.e., uncertainty-averse), but reacts to exogenous uncertainty in a partly pessimistic way by putting a weight on bad outcomes and in a partly optimistic way by putting a weight on good outcomes.

Proposition 3.3 *The game has the following symmetric Equilibrium under Uncertainty:*

1. *If Player i believes that Player $-i$ might contribute $0ECU$ and has beliefs such that $\delta_i(1-\alpha_i) < \frac{1}{3}$ and $\delta_i\alpha_i > \frac{2}{3}$, she should contribute $20ECU$ towards the insurance;*

2. *If Player i believes that Player $-i$ might contribute $10ECU$ and has beliefs such that $\delta_i(1-\alpha_i) < \frac{1}{2} < \delta_i\alpha_i$, she should contribute $20ECU$ towards the insurance.*

Proof.

Part 1. If Player 1 believes that Player 2 will contribute nothing ($0ECU$), she has two options - she can either contribute nothing herself or she can contribute $20ECU$ to ensure that the

[5] We use the convention that female pronouns denote Player 1 and male pronouns denote Player 2. Of course this convention is for convenience only and bears no relation to the actual gender of subjects in the experiments.

threshold is reached and she gets a guaranteed payoff of $\hat{V}_1 = 10$. If she too contributes nothing, the maximum payoff she can earn is $30ECU$, if the climate event does not occur; else, if the catastrophe occurs her payoff is $0ECU$. If δ_1 and α_1 reflect Player 1's endogenous and exogenous ambiguity parameters respectively and π_2^* is the probability with which Player 2 contributes $0ECU$, Player 1's CEU from contributing nothing will be:

$$\begin{aligned} V_1^* &= \delta_1 [\alpha_1 \cdot 0 + (1 - \alpha_1) \cdot 30] + (1 - \delta_1)(30 \cdot \pi_2^*) \\ &= 30\delta_1(1 - \alpha_1) + 30(1 - \delta_1)\pi_2^*. \end{aligned}$$

Player 1 will prefer to contribute $20ECU$ iff:

$$\begin{aligned} V_1^* &< 10 \\ 30\delta_1(1 - \alpha_1) + 30(1 - \delta_1)\pi_2^* &< 10 \\ \delta_1(1 - \alpha_1) + (1 - \delta_1)\pi_2^* &< \frac{1}{3}. \end{aligned}$$

Based on Player 1's belief of π_2^*, $\hat{V}_1$ is strictly preferred iff: $\delta_1(1 - \alpha_1) < \frac{1}{3}$ and $\delta_1\alpha_1 > \frac{2}{3}$. Thus, if Player 1 is sufficiently uncertain she should contribute $20ECU$, in order to ensure that the threshold is reached.

Similarly, let the probability with which Player 1 contributes $0ECU$ be π_1^*, while δ_2 and α_2 reflect Player 2's endogenous and exogenous ambiguity parameters respectively. Player 2 should also contribute $20ECU$, if he is sufficiently uncertain about the safety threshold being reached, i.e., if $\delta_2(1 - \alpha_2) < \frac{1}{3}$ and $\delta_2\alpha_2 > \frac{2}{3}$

Part 2. Let the probability with which Player 2 contributes $10ECU$ be $\tilde{\pi}_2$, while δ_1 and α_1 reflect Player 1's endogenous and exogenous ambiguity parameters respectively. If Player 1 contributes $10ECU$: The maximum payoff, if the threshold is reached, is $20ECU$. Else, if the threshold is not reached and the climate change catastrophe occurs, the payoff is $0ECU$. The CEU of Player

1 from contributing $10ECU$ can be computed as:

$$\begin{aligned} \tilde{V}_1 &= \delta_1 [\alpha_1 \cdot 0 + (1-\alpha_1) \cdot 20] + (1-\delta_1)(20 \cdot \tilde{\pi}_2) \\ &= 20\delta_1(1-\alpha_1) + 20(1-\delta_1)\tilde{\pi}_2. \end{aligned}$$

Alternatively, if Player 1 contributes $20ECU$ the threshold is *always* reached and she has a secure payoff of $10ECU$. The CEU of Player 1 from contributing $20ECU$ is thus: $\hat{V}_1 = 10$. Player 1 will prefer to contribute $20ECU$ iff:

$$\begin{aligned} \tilde{V}_1 &< 10 \\ 20\delta_1(1-\alpha_1) + 20(1-\delta_1)\tilde{\pi}_2 &< 10 \\ \delta_1(1-\alpha_1) + (1-\delta_1)\tilde{\pi}_2 &< \frac{1}{2}. \end{aligned}$$

Based on Player 1's belief of $\tilde{\pi}_2$, $\hat{V}_1$ is strictly preferred iff: $\delta_1(1-\alpha_1) < \frac{1}{2} < \delta_1\alpha_1$. Thus, if Player 1 is sufficiently uncertain she should contribute $20ECU$, in order to ensure that the threshold is reached.

Similarly, let the probability with which Player 1 contributes $10ECU$ be $\tilde{\pi}_1$, while δ_2 and α_2 reflect Player 2's endogenous and exogenous ambiguity parameters respectively. Player 2 should also contribute $20ECU$, if he is sufficiently uncertain about the safety threshold being reached, i.e., if $\delta_2(1-\alpha_2) < \frac{1}{2} < \delta_2\alpha_2$. ∎

Proposition 3.4 *The game has the following asymmetric Equilibrium under Uncertainty: If Player i believes that Player $-i$ might contribute $x_{-i}ECU$ where $x_{-i} \in [0, 20]$ and has beliefs such that $\delta_i(1-\alpha_i) < \frac{10}{10+x_{-i}}$ and $\delta_i\alpha_i > \frac{x_{-i}}{10+x_{-i}}$, she should contribute $20ECU$ towards the insurance.*

Proof. With uncertainty, if Player 1 expects her opponent to contribute x_2ECU towards the insurance with probability $\tilde{\pi}_2$, where $x_2 \in [0, 20]$; then she should contribute $(20 - x_2)ECU$ in order to reach the threshold. The maximum payoff she would expect in this scenario is $(10 + x_2)ECU$ if the threshold is reached. The minimum payoff if the threshold is not reached and the event occurs is $0ECU$. The CEU for Player 1 can be computed as:

$$\check{V}_1 = \delta_1 \left[\alpha_1 \cdot 0 + (1-\alpha_1)\cdot(10+x_2)\right] + (1-\delta_1)(10+x_2)\cdot\breve{\pi}_2$$
$$= \delta_1(1-\alpha_1)(10+x_2) + (1-\delta_1)(10+x_2)\breve{\pi}_2.$$

Player 1 will prefer to contribute $20ECU$ and get the resultant guaranteed payoff of $\hat{V}_1 = 10$, iff:

$$\check{V}_1 < 10$$
$$\delta_1(1-\alpha_1)(10+x_2) + (1-\delta_1)(10+x_2)\breve{\pi}_2 < 10.$$

Based on Player 1's belief of $\breve{\pi}_2$, $\hat{V}_1$ is strictly preferred if: $\delta_1(1-\alpha_1) < \frac{10}{10+x_2}$ and $\delta_1\alpha_1 > \frac{x_2}{10+x_2}$.

The equilibrium under uncertainty for Player 2 is symmetric to that of Player 1. If the probability with which Player 1 contributes x_1ECU is $\breve{\pi}_1$, where $x_1 \in [0,20]$; while δ_2 and α_2 reflect Player 2's endogenous and exogenous ambiguity parameters respectively. Player 2 should also contribute $20ECU$, if he is sufficiently uncertain about the safety threshold being reached, i.e., if $\delta_2(1-\alpha_2) < \frac{10}{10+x_1}$ and $\delta_2\alpha_2 > \frac{x_1}{10+x_1}$. ■

The testable hypothesis that arises from this discussion is that while Nash equilibrium predicts that subjects should contribute either $0ECU$ or $10ECU$, equilibrium under uncertainty suggests that subjects who are uncertainty-averse would contribute greater than $10ECU$ in total, in order to ensure that the safety threshold is reached.

4 Experimental Design

The experiment was coded using z-Tree software (Fischbacher (2007)) and was "framed", explicitly mentioning a climate change catastrophe. However, the findings would also be applicable to any other low-probability high-impact event that was not weather related.

The experimental sessions were conducted at the Finance and Economics Experimental Laboratory in Exeter (FEELE), UK between October 2015 and May 2016. A total of 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.

The experiment could have been run as a one-shot game, but was planned to consist of five rounds to reflect that insurance premiums are paid over a few periods rather than as a one-time lump sum payment. Subjects could not communicate with each other during the experiment and received no information about their team member's contribution decisions between rounds - therefore, there was no opportunity to update beliefs.

Subjects first read through a short, comprehensive set of instructions at their own pace.[6] The subjects were then asked to fill out practice questions to check that they understood the game 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. The provision threshold was common knowledge among the participants. Four treatments were employed as under:

Treatment I (base treatment) - Subjects were randomly assigned to teams of two and remained in the same team throughout the experiment. Each member was given an endowment of 30ECU and played 5 rounds as part of the experiment. Subjects were informed that the climate change catastrophe might occur with some unknown probability. If the catastrophe occurred, both team members would lose all their money. They could protect their team against such a loss, if they decided to purchase a Climate Change Insurance Policy. In each round, a subject could contribute between 0-4 ECU from his/her endowment to a team "pot". The insurance was purchased if the pot contained at least 20 ECU at the end of the 5 rounds.

The base treatment was designed to analyse whether individuals were sufficiently concerned by

[6] The experimental protocols are available in the Appendix.

climate change catastrophes in order to successfully insure themselves. All subsequent treatments were variations of Treatment I as below:

Treatment II (information treatment) - In this treatment, subjects were informed that in the past few periods, climate change catastrophes were known to have struck at least 80% of the time. Subjects were thus given additional information about the probability with which catastrophes had occurred in the experimental sessions that had already been conducted. 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* uncertain. The frequency with which a flood/storm has impacted an area, makes it more likely that it might happen again, but does not guarantee the event occurring each period. The individual's attitude to exogenous uncertainty (regarding the climate event) is represented by the parameter α_i, with higher values of α_i corresponding to the belief that the catastrophe is more likely to take place. As such, $\alpha_i = 1$ would denote pure pessimism with respect to the climate event i.e., a belief that the event will definitely take place, while $\alpha_i = 0$ would denote pure optimism about the chances of the catastrophic event taking place i.e., a belief that the event will definitely not take place. When given the additional information about the likelihood of the event taking place, individuals would update their prior belief α_i, to a new belief $\alpha_i^{'}$, that takes into account the additional information. The aim of this treatment is to check whether information about the increased frequency of weather-related catastrophes leads to an increase in the insurance contributions and to check for the emergence of a lemons market where a lot of (self-perceived) high-risk types buy the insurance.

Treatment III (computer treatment) - Participants in this treatment are matched with a computer, analogous to Bohnet *et al.* (2008) who consider a trust game/risky dictator game rather than a threshold public goods game with uncertainty. Subjects were informed that they had been assigned to a team, where a computer programmed to contribute $2ECU$/round, was the other player, and that they should not expect the computer to deviate from this strategy. Participants who are matched against a computer would not face the strategic (endogenous) uncertainty of coordinating with another player. This treatment therefore strictly captures the reaction to exogenous uncertainty regarding the climate change event. Player 2 (the computer) always contributes $10ECU$, therefore, Player 1 should either contribute $0ECU$ or $10ECU$. If Player 1 contributes $10ECU$, she has a secure payoff of $20ECU$ (since the computer is assured to pay the balance required to reach the threshold). If Player 1 contributes $0ECU$, her expected payoff is:

$$\ddot{V}_1 = [\alpha_1 \cdot 0 + (1 - \alpha_1) \cdot 30]$$

$$\ddot{V}_1 = (1 - \alpha_1) \cdot 30,$$

with higher values of α_1 corresponding to the belief that the catastrophe is more likely to take place. Player 1 would strictly prefer to contribute $10ECU$ iff: $(1 - \alpha_1) \cdot 30 < 20$ or $\alpha_1 > \frac{1}{3}$. Thus in Treatment III, Player 1 should either contribute $0ECU$ if $\alpha_1 < \frac{1}{3}$, or $10ECU$ if $\alpha_1 > \frac{1}{3}$. At $\alpha_1 = \frac{1}{3}$, she is indifferent between purchasing the insurance or not purchasing it.

Treatment IV (nudge treatment) - This treatment was designed to simulate an indirect policy intervention or nudge, such that subjects were automatically enrolled to a pre-assigned contribution level of $2ECU$[7] per round. If subjects were dissatisfied with this automatic assignment, they needed to take conscious (and concrete) steps to opt off it. Subjects could not opt-off as a result of a *tremble,* but could do so by solving a simple mathematics question correctly in order to deviate from the pre-assigned selection. Similarly, subjects who wanted to deviate from the pre-assigned contribution levels to *increase* their contributions also had to perform the simple task, in order to ensure that the deviation was not a tremble/mistake, but consciously determined. This is consistent with the real world, where individuals who want to make higher rate contributions (towards a pension or insurance) need to be proactive in order to sign up to the higher rate.

Once subjects had made all the decisions, the result screen informed subjects about how much

[7] The pre-assigned contribution level, is the contribution level predicted by the efficient symmetric Nash equilibrium (also the Nash that would be consistent with fairness constraints).

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. The computer used a random algorithm to simulate whether the climate change catastrophe had occurred (or not), and calculated the final payoff in ECU and GBP, for each subject. Subjects were paid a show-up fee of £3, together with their earnings, where $5ECU = £1$.[8] Average payoffs per treatments were as follows: Treatment I - £5.50, Treatment II - £6, Treatment III - £6.40 and Treatment IV - £5.50.[9]

5 Data Analysis and Discussion

The experiment consisted of five rounds to reflect that insurance premiums are paid over a few periods rather than as a one-time lump sum payment. The total amount paid by the subject towards the insurance (over the five rounds) is used to classify their behaviour (See Table 1). Subjects contributing less than $10ECU$ form Group A, subjects contributing exactly $10ECU$ (or the contribution level predicted by the efficient symmetric Nash) fall in Group B, and subjects contributing more than $10ECU$ (or those conforming with the equilibrium under uncertainty prediction) fall in Group C. 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 2 (0.28%) subjects who were consistent with the equilibrium under uncertainty prediction and contributed $20ECU$ towards the insurance.[10]

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 2 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

[8] Participants' show-up fee was not affected by the climate change catastrophe.
[9] Payoffs were rounded up to the nearest $20p$, for the purpose of payment.
[10] Only two subjects contributed $20ECU$: one played in Treatment I and the other in Treatment IV.

that failed to reach the threshold. Table 3 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.

In Treatment I (the base treatment), two-thirds of the groups (60 groups) successfully purchased the insurance. This indicates 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 1, it can be noted that approximately 21% of subjects (Group A) either tried to coordinate asymmetrically or were happy to free-ride on others' contributions; 52% of subjects (Group B) attempted to coordinate in order to achieve the efficient symmetric Nash and 26% (Group C) made contributions that were consistent with the equilibrium under uncertainty. It is clear that a majority of subjects conform to the symmetric Nash equilibrium, 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)), such that subjects willingly bear the burden of purchasing the insurance on their own, in order to safeguard the team as a whole.

Since there was no reimbursement of contributions, contributing both more and less than necessary to reach the threshold is inefficient. Table 4 summarises the number of groups who contributed inefficiently. It can be noted that in Treatment I, about 66.67% of groups made inefficient contributions towards the insurance.

Table 1: Individual Contribution Levels

	Subjects	Group A		Group B		Group C	
		Cont. <10ECU		Cont. =10ECU		Cont. >10ECU	
Treatment I	n=180	38	21.11%	94	52.22%	48	26.67%
Treatment II	n=192	24	12.50%	105	54.69%	63	32.81%
Treatment III	n=153	29	18.95%	97	63.40%	27	17.65%
Treatment IV	n=194	53	27.32%	96	49.48%	45	23.20%
Overall		144	20.03%	392	54.52%	183	25.45%

In Treatment II (information treatment), subjects were found to take the additional information on board and this resulted in an increase in the number of groups that successfully purchased the

Table 2: Success in buying the Climate Change Insurance

	Treatment I	Treatment II	Treatment III	Treatment IV
Number of groups	90	96	153	97
Groups reaching threshold	60	76	124	57
Groups not reaching threshold	30	20	29	40
% of successful groups	66.67%	79.17%	81.05%	58.76%

Table 3: 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.	

insurance to 79.17% (76 groups). A Fisher exact test[11] shows that there is a significant increase in the number of groups purchasing the insurance, when compared to the base treatment ($P = 0.069$). This indicates that if individuals are given access to information that shows that the frequency of climate change catastrophes in their area is increasing, they would update their beliefs and insure more often. Theoretically, if the information revealed that the frequency of climate change catastrophes in their area is decreasing/low, it would reduce the number of insurance subscriptions. However, this might lead to a lemons problem emerging in the climate change insurance market, such that only high-risk customers are insured. Private insurers would not be willing/able to pool risks efficiently in such a scenario. Asymmetric subscriptions may result in the need for government intervention, in order to improve the market outcome. In terms of efficiency, Treatment II does not differ much from the base treatment (See Table 4). About 66.67% of groups made inefficient contributions, with a majority of the groups over-contributing towards the insurance.

In Treatment III (computer treatment), 81.05% (124 subjects) successfully reached the required threshold - i.e., when the strategic uncertainty of coordination was removed, the number of subjects purchasing the insurance increases. When compared to the base treatment, a Fisher exact test[12]

[11] (H_0: The proportion of groups buying insurance in Treatment I and II are identical, H_1: The proportion of groups buying insurance in Treatment II is greater than in Treatment I.)

[12] (H_0: The proportion of groups buying insurance in Treatment I and III are identical, H_1: The proportion of groups buying insurance in Treatment III is greater than in Treatment I.)

Table 4: Efficiency Analysis

	Cont. $< 20ECU$	Cont. $> 20ECU$	Total Ineff. Groups	Total Groups	Inefficiency Rate
Treatment I	30	30	60	90	66.67%
Treatment II	20	44	64	96	66.67%
Treatment III	29	27	56	153	36.60%
Treatment IV	40	29	69	97	71.13%
Overall	119	130	249	436	57.11%

shows that there is a significant increase in the number of subjects purchasing the insurance in Treatment III ($P = 0.014$). Under Treatment III, if subjects are not concerned about the climate change catastrophe (i.e., if they have an $\alpha_i < \frac{1}{3}$), they should contribute $0ECU$. The data for this treatment, finds that 6 subjects contributed $0ECU$ towards the insurance, indicating that this small minority (3.92%) of subjects did not find the catastrophe a matter of concern. In this treatment, it is irrational 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. Overall, this was the most efficient treatment.

In Treatment IV (nudge treatment) it was found that the number of groups successfully purchasing the insurance (58.76% or 57 groups) was lower than in the base treatment. It is very interesting to note that policy intervention/nudge seems to have backfired - i.e., subjects exerted an effort to opt-off the pre-assigned contribution level. A Fisher exact test[13] 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 may have even caused a "rebellious" behaviour on the part of subjects. This is termed as a "*boomerang effect*" in psychology, where an attempt to persuade a subject, results in the unintended consequence of him adopting an opposing position instead. The boomerang effect phenomenon was first identified by Brehm & Brehm (1981) and has since been documented in other studies considering individual behaviour in socio-economic situations (See Werch *et al.* (2000), Wechsler *et al.* (2003), Perkins *et al.* (2005), Schultz *et al.* (2007), Allcott (2011)).

[13](H_0: The proportion of groups buying insurance in Treatment I and IV are identical, H_1: The proportion of groups buying insurance in Treatment IV is greater than in Treatment I.)

In the current study, 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 willing 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. In terms of efficiency, Treatment IV was the most inefficient treatment (See Table 4), with about 71.13% of groups making inefficient contributions - a bulk of these groups under-contributing towards the insurance.

The standard Ellsberg (1961) urn question[14] was posed to subjects, in order to determine their attitude towards uncertainty. For an extensive survey of the literature on Ellsberg experiments, see Trautmann & van de Kuilen (2016). In the current study, the Ellsberg urn question posed to the subjects was not incentivised. For other papers that also assume that non-incentivised Ellsberg-style thought experiments reveal true preferences see Butler *et al.* (2014) and Bianchi & Tallon (2016). Cavatorta & Schröder (2016) conduct a comprehensive study that provides empirical support to the assumption that unincetivised thought experiments are significantly correlated to uncertainty preferences that are obtained in incentivised decision tasks.

Dummy variables were defined for the various treatments (Treatment I, Treatment II, etc.) and to capture subjects' attitude to uncertainty (Uncertainty-Averse/Seeking). A probit regression was run to ascertain what factors increased the likelihood of the insurance being bought. Table 5 provides the results of a probit regression of "*Insurance Bought*" on the various treatment and uncertainty-attitude dummies. The dummy for Treatment I and uncertainty-seeking attitude were dropped from the probit regression, in order to avoid the problem of collinearity. Dummies for degree/subject studied at university of subjects, age and gender were found to be insignificant and were thus dropped

[14] 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 or a payoff of 100 if a ball labelled Y is drawn." Subjects who are uncertainty-averse should choose to bet on balls labelled X, as their quantity is known. Subjects who are not uncertainty-averse would be expected to choose to bet on balls labelled Y, whose quantity is unknown.

from the final regression.[15] The final regression has a chi-square ratio of 36.55 with a p-value of 0.0000, which indicates that the model as a whole is statistically significant.

Table 5: Probit Regression Results

Variable	Coefficient	Std. Err.	z	$P > \|z\|$	[95% Conf. Interval]	
Treatment II	.3794556***	.1412632	2.69	0.007	.1025848	.6563264
Treatment III	.4310939***	.1526451	2.82	0.005	.1319151	.7302728
Treatment IV	−.2192589*	.1330922	−1.65	0.099	−.4801149	.0415971
Uncertainty Averse	.2946323***	.1113287	2.65	0.008	.076432	.5128325
Constant	.2259345*	.1239068	1.82	0.068	−.0169183	.4687873
*, **, *** indicate significance levels of 10%, 5% and 1% respectively.						

The coefficients from a probit regression do not have the same interpretation as coefficients from an Ordinary Least Squares regression. From Table 5, we can interpret that in Treatment II the z-score increases by 0.38, making it more likely for the insurance to be bought than in the base treatment. Similarly in Treatment III, the z-score increases by 0.43, but in Treatment IV the z-score decreases by 0.219, compared to the base treatment. Treatment IV was only significant at 10% while Treatments II and III were significant at 1%.

It can be concluded that Treatments II and III provide situations where the insurance is more likely to be purchased, while Treatment IV hampers contributions. Moreover if a subject is uncertainty-averse in the classic Ellsberg urn situation, the z-score increases by 0.29, making it significantly more likely for the insurance to be purchased than the reference group (uncertainty-seeking people). This is in line with the hypothesis that uncertainty-aversion would make individuals more likely to contribute towards a climate change insurance.

6 Conclusion

Overall, subjects' behaviour was consistent with Nash equilibrium, however, a sizable minority of subjects did display behaviour consistent with an uncertainty-averse attitude. It is important to

[15] This information is collected as standard practice for all subjects who take part in experiments at FEELE.

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 an increase in coordination failures and/or increase in contributions fuelled by uncertainty-averse behaviour (since strategic uncertainty can be seen to increase with group-size).

A majority of subjects do reach the threshold required to insure themselves against the climate change catastrophe. This indicates that individuals are concerned about climate change and the resultant impact it may have 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, with premiums that reflect the low frequency/high-impact nature of climate events, which have a long tail in terms of liabilities.

An insurance of this type would require a widespread up-take, in order to sufficiently cross-insure risks across geographical regions and make it feasible from the insurance companies' point of view. Increasing the availability of information about the frequency of climate change catastrophes in the past (Treatment II), leads to a significant increase in insurance subscriptions amongst those individuals who perceive themselves to be at a high-risk of becoming victims. Unless individuals perceived to live in "high-risk" areas, are cross-insured by individuals living in "low-risk" areas, insurance companies would find that all their customers were lemons and would quickly go out of business. Government intervention may thus be required in order to improve the market outcome in the presence of asymmetric subscriptions.

Treatment III finds that removing the strategic uncertainty of contribution towards the insurance results in a significant increase in insurance subscriptions. Interestingly, an indirect policy intervention in the form of a "nudge" does not have the intended effects. The nudge was in fact found to be counter-productive and may have resulted in a fall in subscriptions. In terms of efficiency, again, removing the strategic uncertainty of others' contributions (Treatment III) provides the best results, while the indirect policy intervention was least efficient.

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 threshold. In reality, insurance premiums would increase to reflect the growing frequency of the catastrophe. 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 uncertainty-attitude of a subject.

Climate change and its allied effects are becoming inevitable, and 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. Further investigations may be required to ascertain more direct mechanisms that would ensure a better outcome.

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