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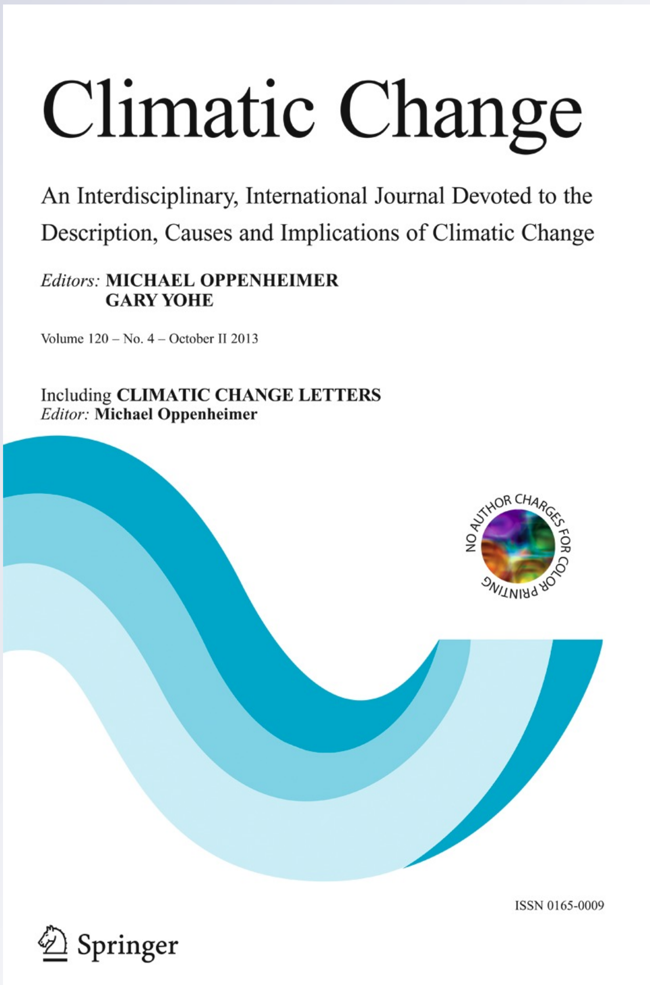

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Combined inequality in wealth and risk leads to disaster in the climate change game

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Abstract It is generally agreed that the risk of catastrophic climate change can only be reduced if agents cooperate to reduce greenhouse gas emissions over the course of the 21st Century. Previous economic experiments have suggested that sufficient cooperation can often be achieved providing individuals are adequately and convincingly informed of the consequences of their actions and the stakes involved. However, this previous work, has not allowed for the fact that in the real world agents vary in both: (1) their resources to mitigate climate change, and (2) the consequences that they face from climate change. We develop and expand the protocol of previous economic experiments to investigate the introduction of such combined asymmetries. We find that when inequality in resources is combined with a greater relative risk for poorer members, cooperation collapses, with tragic consequences. This is because the rich invest proportionally less into preventing climate change when they are less at risk. We also find, through the use of a post-game questionnaire, that those individuals who were more skeptical about climate change in the real world cooperated less in our games. Insofar as such experiments can be trusted as a guide to either people's everyday behaviour or the interactions of nation states, these results suggest that voluntary cooperation to avoid climate catastrophe in the real world is likely to be hard to achieve.

1 Introduction

It is generally agreed that the risk of catastrophic climate change can only be reduced if nations cooperate to reduce greenhouse gas emissions over the course of the 21st Century (King 2004; Metz and Intergovernmental Panel on Climate Change. Working Group III

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2007; Parry and Intergovernmental Panel on Climate Change. Working Group II 2007; Solomon and Intergovernmental Panel on Climate Change. Working Group I 2007; Stern 2007; Stott et al. 2010; Turner et al. 2010). The problem is that although cooperating as a group to reduce greenhouse gas emission would be the best long-term option, the short-term gain from exploiting resources or 'free-riding' can lead to individual agents (be they people, businesses, or nation states) not doing this. One of the most important challenges of our time therefore is to determine how this 'tragedy of the commons' can be overcome and the risk of destructive climate change mitigated (Hardin 1968).

The problem of addressing climate change can be investigated both theoretically and experimentally, as a public goods or collective action game (Buchan et al. 2009; Dutta and Radner 2004, 2009; Eyckmans and Tulkens 2003; Mendelsohn et al. 2000; Milinski et al. 2006, 2008, 2011; Nordhaus and Yang 1996; Olson 1965; Tavoni et al. 2011; Tol 2002a, b). One way to do this is to suppose a group of individuals, each of which is given an amount of money, and that a fraction of this can be contributed to a 'climate account' (Milinski et al. 2008). If the group as a whole invests sufficient money into the climate account, then severe climate change is prevented, and thus no catastrophic climate events can happen, and therefore each individual keeps their remaining money. In contrast, if insufficient resources are invested into the climate account, then severe climate change occurs and there is a possibility that a catastrophic climate event happens, in which case the players lose all their remaining money.

The problem in such "collective-action resource-dilemmas" is that while all players might want to avoid the catastrophe, individuals will do better by under investing (cheating), providing that the other players make the necessary contributions to the climate account. Milinski et al. (2008) examined this experimentally in a climate change game where decisions are parceled into 10 rounds of simultaneous play. They found that if the likelihood of catastrophe is set sufficiently high (P=0.9), then groups invest enough into the climate account approximately 50 % of the time. This suggests that climate catastrophe could maybe be prevented as long as individuals are (1) educated sufficiently about the likelihood and consequences and (2) these consequences are sufficiently certain.

However, most previous experimental work assumed that all individuals were equal, which is far from the case with the countries involved in the real climate game, or among different groups within countries. Countries vary both in the resources that they can invest in preventing climate change, as well as the costs their people will suffer if climate change occurs (Dutta and Radner 2009; Mendelsohn et al. 2000; Nordhaus and Yang 1996; Parry and Intergovernmental Panel on Climate Change. Working Group II 2007; Tol 2002a, b). Specifically, the countries that are likely to experience the greatest damage from climate change also tend to be the poorer countries with less money or resources to put into preventing it (Parry and Intergovernmental Panel on Climate Change. Working Group II 2007; Tol 2002a, b). The same issue occurs within countries, where poorer individuals can also be more vulnerable to the consequences of climate change (Parry and Intergovernmental Panel on Climate Change. Working Group II 2007).

Such inequalities and asymmetries can make cooperative outcomes less likely, as they often introduce multiple fairness equilibria (or competing norms) into economic games, such as equal contributions versus equal outcomes for example (Allison et al. 1992; Allison and Messick 1990; Eek et al. 2001; Kimmerle and Cress 2008; Nordhaus and Yang 1996; Tavoni et al. 2011; Thompson and Loewenstein 1992; Van Dijk and Wilke 1995; Wade-Benzoni et al. 1996). Alternatively, the climate change game can be conceptualized as akin to a volunteer's dilemma (VOD), in which case asymmetries can make cooperative outcomes more likely (Diekmann 1985, 1993). This is because the rich will be more capable of preventing climate change and thus the number of cooperators required is effectively reduced. The same applies for heterogeneity in risk, with those more at risk being more willing to prevent climate change as they have the most to lose. However, if such heterogeneities are combined, then predicted outcomes differ depending on if it is the rich or the poor that are likely to suffer the most. Specifically, if the rich are most at risk then climate change is most likely to be prevented, as the rich will be both more capable and more interested in preventing climate change. In contrast, if the poor are most at risk then the relative power (resources) to prevent climate change will be decoupled from the costs (risks) of climate change, and the spending threshold is less likely to be met.

Although two recent studies have included resource heterogeneity in their design, one did not include a comparison with egalitarian groups that enabled a direct test of inequality per se (Milinski et al. 2011), and neither of them included different risks for rich and poor if climate change occurs (Milinski et al. 2011; Tavoni et al. 2011) (see discussion for further comparisons). Here, we experimentally test the effect of inequality in both resources and risk, by carrying out a climate change game with four different treatments whereby the financial power and consequences of climate catastrophe vary among the players (Fig. 1). As done so by Milinski et al. (2008) we endowed our six-person groups collectively with 240 MU (monetary units) and told them that they had to collectively donate 120 MU (50 %) or more in order to prevent severe climate change, or else they would all risk losing all and any saved MU in a catastrophic climate event. In contrast to Milinski et al. (2008), we had three additional, non-egalitarian, treatments whereby we varied financial resources (and thus interests) by asymmetrically distributing the group endowment.

For each group we randomly created two 'rich' members (with 80 MU each) and four 'poor' members (with only 20 MU each). We also varied the consequences of climate change for the rich and poor in two of these non-egalitarian treatments by introducing an asymmetry into the probabilities of subsequent catastrophic climate events (imagine catastrophic climate events are localized), with either the rich or poor at a relatively greater risk (Fig. 1, also see Methods). Although we model the consequences of a catastrophic climate event as the same for all types of player (resources entirely wiped out), rather than as different degrees of loss, we do vary the probability of such an event occurring for the different types. In this way we simulate a scenario whereby the expected damage varies, on average, for different types. This is akin to global climate change occurring but the catastrophic events occurring predominantly in some locations.

2 Methods

2.1 Experimental design and procedure

We had 32 groups of six participants (104 men and 88 women). We tested four versions of the "collective-risk social dilemma" as developed by Milinski et al. (2008) (Fig. 1, Tables 1 and 2). The four versions were (1) Egalitarian, in which all six players had the same endowment (40 MU) and faced the same risk P of catastrophic events (either P=0.7 or 0.8, see below); (2) Unequal-wealth, the same, uniform risks as in the egalitarian treatment, but this time two players received 80 MU and the remaining four players only 20 MU; (3) Rich-suffer, which had the same non-egalitarian distribution of endowments, but whereby the rich were at greater relative risk (P=0.95 or 0.90, see below) than the poor (P=0.65 and 0.50

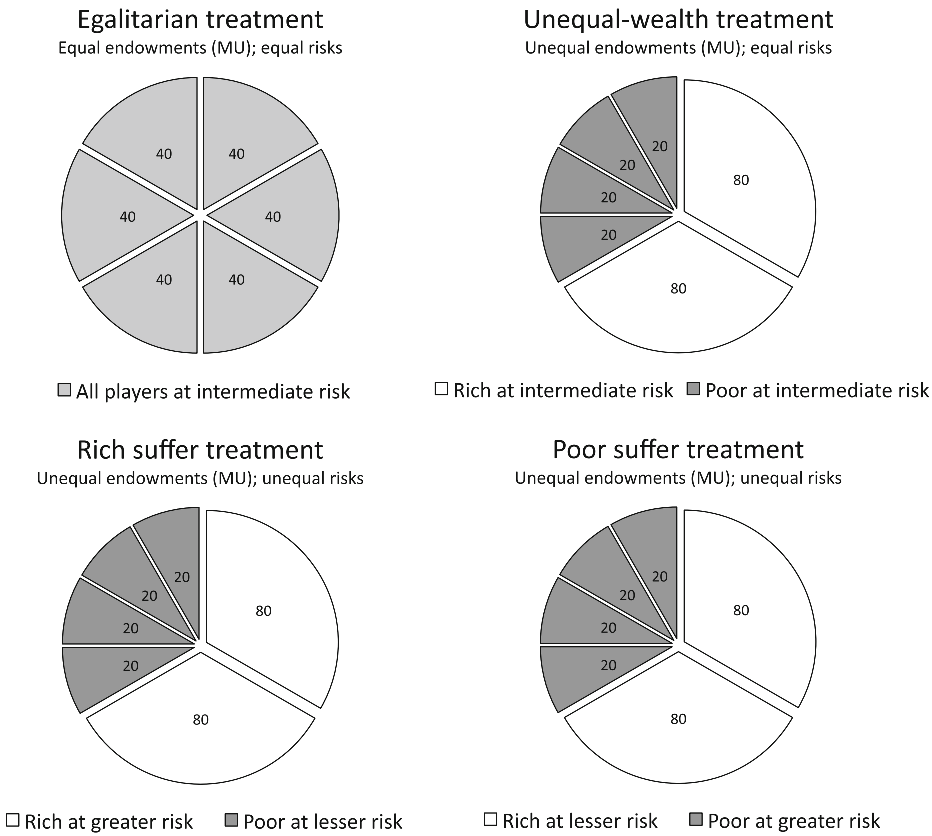

Fig. 1 Experimental design: resources and risk. We divided 240 MU (monetary units) amongst six participants in either an egalitarian (40 MU each) or non-egalitarian (two 'rich' players get 80 MU, and four 'poor' players get 20 MU) manner. Participants had to decide how much of their endowment to keep for themselves and how much to invest into preventing climate change. If groups failed to collectively invest 120 MU or more into a climate change account, then there was a risk P of a catastrophic climate event, in which case any unspent MU were reduce to zero. In two treatments, (egalitarian and unequal-wealth), the risk of a catastrophic climate event was the same for all participants (P=0.8 or 0.7). In the other two treatments, the risk of a catastrophic climate event was higher for either the rich (rich suffer) or the poor (poor suffer) members of the group (Tables 1 and 2)

respectively); and (4) Poor-suffer, which was the same as the rich-suffer, except that the relative risks were reversed for rich and poor.

We split the 32 groups across two experimental blocks, both with the same distribution of endowments, but with one block having a higher mean level of risk and the other block having a more extreme difference in risk than the other. Specifically, for Block A, we set the mean level of risk at P=0.8, with the equal risk groups at P=0.8 and the relatively low and high-risk groups at P=0.65 and P=0.95 respectively. Alternatively, for Block B we set the mean level of risk at P=0.7, with the equal risk groups at P=0.7 and the relatively low and high-risk groups at P=0.5 and P=0.9 respectively.

In keeping with the original design of Milinski et al. (2008), every game was 10 rounds long and participants could only invest a maximum of 10 % of their endowment per round. After each

Table 1 A breakdown of 'fair' Nash equilibria and the associated contribution levels with corresponding payoffs, alongside the actual data and group performance. This table is for the 16 groups that played with a relatively higher level of risk (block A)

Game[a]	Player type	Risk	'Fair' Nash equilibria strategies[b]				Rational limit[d]	If other type plays limit[e]	Actual spending and group performance[f]		
			Spent MU beget –>[c] Expected payoff								
			(1) Defect - zero	(2) Cooperate equal proportion	(3) Cooperate equal costs	(4) Cooperate equal outcomes			Mean overall spending: individual within (type)	Mean initial spending (max.)	Group totals (success =>120)
	Equal (40 MU)	0.8	0–>8	20–>20	20–>20	20–>20	32–>8	n/a	16.3 (98)	1.5 (4)	
Eg	GROUP		0–>48	120–>120	120–>120	120–>120	120–>120		98–>28.4	9 (24)	25, 120, 121, 126
	Rich (80 MU)	0.8	0–>16	40–>40	20–>60	60–>20	64–>16	28–>52	44.9 (89.8)	4.4 (8)	
	Poor (20 MU)	0.8	0–>4	10–>10	20–>0	0–>20	16–>4	0–>20	7.8 (31.3)	1 (2)	
U-w	GROUP		0–>48	120–>120	120–>120	120–>120			121.1–>118.9	12.8 (24)	118, 121, 122, 123
	Rich (80 MU)	0.95	0–>4	40–>40	20–>60	60–>20	76–>4	34–>46	51.1 (102.3)	4.3 (8)	
	Poor (20 MU)	0.65	0–>7	10–>10	20–>0	0–>20	13–>7	0–>20	3.4 (13.8)	0.6 (2)	
R-s	GROUP		0–>36	120–>120	120–>120	120–>120			116.1–>24.8	11 (24)	102, 114, 124, 124
	Rich (80 MU)	0.65	0–>28	40–>40	20–>60	60–>20	52–>28	22–>58	27 (54)	2.9 (8)	
	Poor (20 MU)	0.95	0–>1	10–>10	20–>0	0–>20	19–>1	8–>12	8.4 (33.5)	0.8 (2)	

Table 1 (continued)

Game[a]	Player type	Risk	'Fair' Nash equilibria strategies[b] Spent MU beget ->[c] Expected payoff				Rational limit[d]	If other type plays limit[e]	Actual spending and group performance[f]		
			(1) Defect - zero	(2) Cooperate equal proportion	(3) Cooperate equal costs	(4) Cooperate equal outcomes			Mean overall spending: individual within (type)	Mean initial spending (max.)	Group totals (success =>120)
P-s	GROUP		0–>60	120–>120	120–>120	120–>120			87.5–>31	9 (24)	47, 91, 100, 112

[a] *Eg* Egalitarian; *U-w* Unequal-wealth; *R-s* Rich-suffer; *P-s* Poor-suffer treatments

[b] 'Fair' Nash equilibiria strategies are Nash equilibria that arguably conform to four fairness norms (3 cooperative); (1) full defection and all spend zero, (2) all spend 50 % of endowment, (3) all spend the same absolute costs (20 MU) regardless of resources, and (4) all spend so as to achieve both the group target and a redistribution of wealth that equalises payoffs

[c] -> shows the expected payoff associated with any strategy. The expected payoff is calculated from the average returns expected given the specific level of risk

[d] This is the limit any rational, self-interested and risk-neutral player should be willing to spend given their resources and personal risk, as otherwise they will be better off fully defecting

[e] This is how much the Rich, or the Poor, have to spend, assuming they split the shortfall evenly, if the other type collectively spends their rational limit

[f] The data shown are the mean spending (MU), over all 10 rounds, for each type of player by treatment, plus what these sum up to for that specific type of player (as there are two rich players and four poor players in each non-egalitarian group). The mean initial spending (for round one) is also shown, along with the maximum spending possible in (brackets). Finally, the actual totals the four groups in each treatment are shown, totals more than or equal to 120 MU were successful

Table 2 A breakdown of 'fair' Nash equilibria and the associated contribution levels with corresponding payoffs, alongside the actual data and group performance. This table is for the 16 groups that played with a relatively lower level of risk (block B)

Game[a]	Player type	Risk	'Fair' Nash equilibria strategies[b]				Rational limit[d]	If other type plays limit[e]	Actual contributions and group performance[f]		
			Spent MU beget ->[c] Expected payoff								
			(1) Defect - zero	(2) Cooperate equal proportion	(3) Cooperate equal costs	(4) Cooperate equal outcomes			Mean overall spending: individual within (type)	Mean initial spending (max.)	Group totals (success =>120)
	Equal (40 MU)	0.7	0–>12	20–>20	20–>20	20–>20	28–>12	n/a	20.2 (121.3)	1.8 (4)	
Eg	GROUP		0–>72	120–>120	120–>120	120–>120			121.3–>118.7	10.8 (24)	120, 121, 122, 122
	Rich (80 MU)	0.7	0–>24	40–>40	20–>60	60–>20	56–>24	32–>48	44.8 (89.5)	3.5 (8)	
	Poor (20 MU)	0.7	0–>6	10–>10	20–>0	0–>20	14–>6	4–>16	5.6 (22.5)	0.6 (2)	
U-w	GROUP		0–>72	120–>120	120–>120	120–>120			112–>38		101, 102, 122, 123
	Rich (80 MU)	0.9	0–>8	40–>40	20–>60	60–>20	72–>8	40–>40	52 (104)	3.4 (8)	
	Poor (20 MU)	0.5	0–>10	10–>10	20–>0	0–>20	10–>10	0–>20	4.9 (19.8)	0.7 (2)	
R-s	GROUP		0–>56	120–>120	120–>120	120–>120			123.8–>116.2		121, 123, 123, 128
	Rich (80 MU)	0.5	0–>40	40–>40	20–>60	60–>20	40–>28	24–>56	31.4 (62.8)	3.9 (8)	
	Poor (20 MU)	0.9	0–>2	10–>10	20–>0	0–>20	18–>2	20–>0	8.4 (33.5)	0.9 (2)	

Table 2 (continued)

Game[a]	Player type	Risk	'Fair' Nash equilibria strategies[b] Spent MU beget ->[c] Expected payoff				Rational limit[d]	If other type plays limit[e]	Actual contributions and group performance[f]		
			(1) Defect - zero	(2) Cooperate equal proportion	(3) Cooperate equal costs	(4) Cooperate equal outcomes			Mean overall spending: individual within (type)	Mean initial spending (max.)	Group totals (success =>120)
P-s	GROUP		0–>88	120–>120	120–>120	120–>120			96.3–>43.1		36, 112, 113, 124

[a] *Eg* Egalitarian; *U-w* Unequal-wealth; *R-s* Rich-suffer; *s* Poor-suffer treatments

[b] 'Fair' Nash equilibiria strategies are Nash equilibria that arguably conform to four fairness norms (3 cooperative); (1) full defection and all spend zero, (2) all spend 50 % of endowment, (3) all spend the same absolute costs (20 MU) regardless of resources, and (4) all spend so as to achieve both the group target and a redistribution of wealth that equalises payoffs

[c] -> shows the expected payoff associated with any strategy. The expected payoff is calculated from the average returns expected given the specific level of risk

[d] This is the limit any rational, self-interested and risk-neutral player should be willing to spend given their resources and personal risk, as otherwise they will be better off fully defecting

[e] This is how much the Rich, or the Poor, have to spend, assuming they split the shortfall evenly, if the other type collectively spends their rational limit

[f] The data shown are the mean spending (MU), over all 10 rounds, for each type of player by treatment, plus what these sum up to for that specific type of player (as there are two rich players and four poor players in each non-egalitarian group). The mean initial spending (for round one) is also shown, along with the maximum spending possible in (brackets). Finally, the actual totals the four groups in each treatment are shown, totals more than or equal to 120 MU were successful

decision was made, participants were informed of the decisions of each of the other five group members, the cumulative group spending so far, and a history of the cumulative group spending over all previous rounds. We also gave them a reminder of the group target, the history of their own spending and how much of their original endowment remained. In order to make our results comparable with those of Milinski et al. (2008), we excluded any possible communication between players.

Finally, we presented our participants with a post-game questionnaire to test if participants general attitude towards climate change in the real world correlated with their within game decisions. If players rationally attempt to maximize their earnings then such beliefs should of course be irrelevant. Our post-game questionnaire featured five statements on climate change and we asked participants to indicate their feeling of agreement with each statement on a 7-point scale (see Online Resource 1).

The exchange rate was 1 MU=£0.50 and the mean earnings were £7.90 (plus £4 show up fee), ranging from a minimum of £0 to a maximum of £25. The sessions were conducted in March 2011 at the Nuffield Centre for Experimental Social Sciences (CESS).

2.2 Statistical analysis

We used a binary-logistic generalized linear model (GLM) to test for the effect of treatment on group level success, and a binomial-logistic GLM to compare the proportional spending of rich versus poor types. As each group had two rich members and four poor members, we took the mean spending of each type to control for pseudo-replication (Hurlbert 1984). To capture an individual's level of general agreement with the questionnaire on real world climate change, we summed their responses to the five questions to give one value, which we then normalized with an arcsine-(square-root) transformation.

3 Results

We found that the proportion of groups in which climate change was prevented was significantly lower in the 'poor suffer' treatment, where there were rich and poor individuals, and the poor were at a greater risk (Fig. 2; GLM: Likelihood ratio $\chi^2=9.46$, df=1, $P=0.002$). Climate change was only prevented in one out of eight groups (13 %) in this poor suffer treatment. This contrasted with the relatively high proportion of groups that were successful in the other three treatments (75 %, 18 out of 24 groups in the other three treatments) (Fig. 2, plus Fig. S1 and S2 in Online Resource 2). There was no significant difference among these three treatments (GLM: Likelihood ratio $\chi^2=0.94$, df=2, $P=0.626$) or between the two experimental blocks (GLM: Likelihood ratio $\chi^2=1.308$, df=1, $P=0.253$).

If we analyze the blocks separately, we still find that the poor-suffer treatment was less successful than the other treatments combined. In block A (mean risk at $P=0.8$), none of the poor suffer groups were successful, versus eight of the other 12 groups ($\chi^2_{(1)}=5.3$, $P=0.0209$, Table 1). In block B (mean risk at $P=0.7$), only one of the poor suffer groups were successful, versus 10 of the other 12 groups ($\chi^2_{(1)}=4.8$, $P=0.0293$, Table 2). Therefore, in the ensuing analysis and figures, we restrict attention to the pooled data across the two blocks.

In summary, across the two blocks, seven of the eight 'egalitarian' groups were successful, as were five of the eight groups that had 'unequal-wealth' but equal risks, and six of the eight groups that had unequal wealth but where the rich were at greater risk of a local

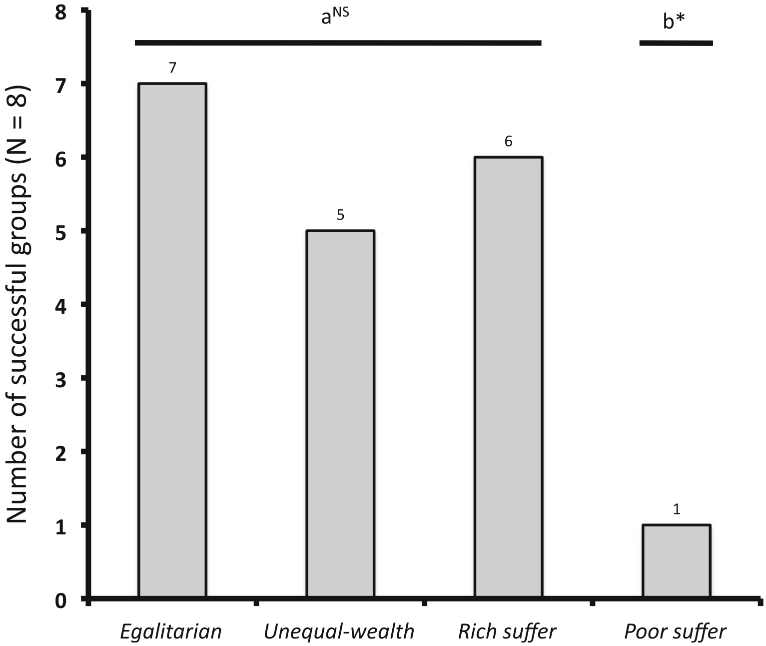

Fig. 2 Cooperation collapses when the poor suffer. The proportion of groups which were successful in preventing severe climate change was significantly lower in the poor suffer treatment (b*, P=0.002), compared with the other three, which were not significantly different (a^{NS}, P=0.626)

catastrophic event. Of the 13 groups that failed across the two blocks, nine had spent 100 MU or more (mean = 108.22±6.87 MU) and thus nearly managed to create, a la the participants of Milinski et al. (2008), '*the worst possible outcome*'.

We found that investment into the climate account depended upon the risk that they faced and their power to prevent climate change. Overall, the rich members of the groups invested proportionally more of their own resources than the poor members of the groups did (Fig. 3; GLM: Likelihood ratio χ^2=28.13, df=1, P<0.001). However, both the rich and the poor contributed less when they suffered a lower personal risk (Fig. 3; GLM: Likelihood ratio χ^2=27.77, df=1, P<0.001). Consequently, in our poor suffer treatment there was no significant difference in the proportion of resources invested by the rich and the poor (Fig. 3; GLM: Likelihood ratio χ^2=0.36, df=1, P=0.548).

We also made our groups play all four treatments sequentially to test for any improvements within sessions with repeated experience of the game. Repeated exposure to the games increased the probability of success (GLM: Likelihood ratio χ^2=4.84, df=1, P=0.028). Overall, combining the four treatments, the probability of success increased from 19 of 32 (59 %) naïve groups in the first round to 26 of 32 (81 %) experienced groups in the fourth round (Fig. S3, Online Resource 2). The biggest change was in the poor suffer treatment, with only 1 of 8 (13 %) naïve groups succeeding, compared to 7 of 8 (87 %) experienced groups in the fourth round. Examining the answers to the questionnaires, we found that individuals who were more skeptical about climate change in the real world (controlling for treatment order and endowment received) surprisingly invested less in our game (Fig. 4; GLM: Likelihood ratio χ^2_1=16.15, df=1, P<0.001).

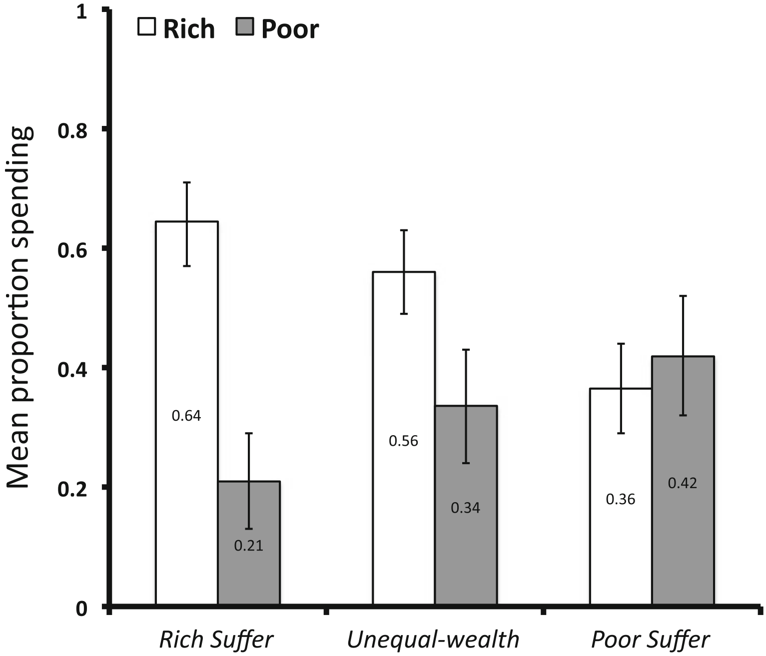

Fig. 3 Investing to prevent climate change. We found that: (1) overall, the rich invested a higher proportion of their resources into preventing severe climate change; and (2) both rich (*N*=8 groups of 2, per treatment) and poor (*N*=8 groups of 4, per treatment) invested less into preventing severe climate change when they were less at risk of a catastrophic climate event. Error bars are 95 % confidence intervals

4 Discussion

Of our four treatments, the one that is arguably the most analogous to the real world is the poor suffer treatment, where there are rich and poor individuals, and the poor are at greater risk from climate change (Parry and Intergovernmental Panel on Climate Change. Working Group II 2007; Tol 2002a, b). We found that groups failed to meet their targets, and thus prevent severe climate change, most often in this treatment (7 out of 8 groups, Fig. 2). The reason for this was that the rich players had the greater economic power to prevent climate change, but that they invested less when they were at lower risk (Fig. 3). Another way of looking at this is that inequality in both resources and risk led to severe climate change, because in the poor suffer treatment, the power (resources) to prevent climate change was decoupled from the cost (risk) of climate change (catastrophic events). However, even when the power to prevent climate change was coupled with the greater risk (rich suffer treatment), only six of eight groups were successful, suggesting that either the two rich players still struggled to cooperate sufficiently, and/or the rich still needed some help from the poor.

The effect of inequality in resources per se had no discernable effect upon our results except when relatively lesser resources were coupled with increased risks. The lack of a simple inequality in wealth effect is in accordance with the mixed results of previous studies addressing fairness norms in public good games (Hofmeyr et al. 2007; Kimmerle and Cress 2008; Milinski et al. 2011; Tavoni et al. 2011; Van Dijk and Wilke 1995). Note that although the rich invested proportionally more on average in our game, this does not require them to be

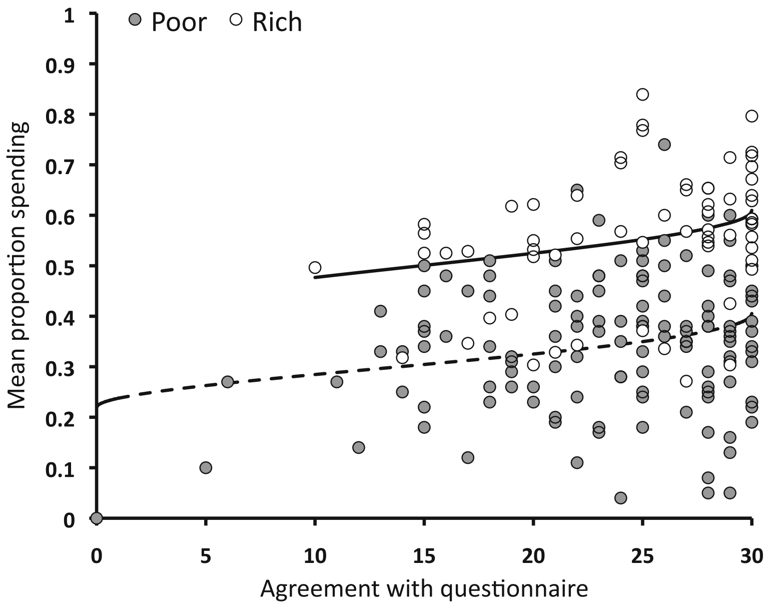

Fig. 4 Beliefs and behaviour. Participants that were more skeptical of climate change and our ability and obligation to prevent it in the real world invested a lower proportion of their endowments in the games. These real-world concerns and beliefs were not relevant to strategic game play, but yet correlated with participants' decisions. *Filled circles* and *dashed line* = poor players' data and logistic regression; *empty circles* and *full line* = rich players' data and logistic regression

'altruistic', sensu Nowak and Dreber (2008), and thus willing to pay for free-riders, but merely that they had more to lose and thus were prepared to pay more in order to protect their relatively large endowments. Ultimately, players of this game are forced to gamble, and to base their decisions upon their beliefs about their group members, and therefore a lack of rationality at the individual level and/or other-regarding preferences cannot easily be inferred from different strategies.

4.1 Fairness and the effect of asymmetries

Although fairness may well play a role in such games, we are not assuming that our participants followed any particular fairness norms. If they did do though, then it is worth nothing that in the original egalitarian treatment of Milinski et al. (2008) there is only one readily apparent fairness norm (apart from full defection) that applies, which is to spend 20 MU each. However this could be a result of one of three fairness norms in action: (1) an "equal proportional costs rule", (2) an "equal absolute costs" rule, or (3) an "equal outcomes" rule (Tables 1 and 2). In all three of our non-egalitarian treatments, these fairness norms predict different spending patterns. For (1) the players would have to each spend 50 % of their endowments (40 MU and 10 MU from each of the two rich and four poor players respectively); for (2) they all would have to spend 20 MU each; and for (3) the rich would have to spend 60 MU each and the poor players would spend 0 MU, to finish the game with 20 MU for each player (Tables 1 and 2). However, the fact that our players, both rich and poor, adjusted their spending according to their relative risks makes it hard to suggests that the players were not merely playing out of self-interest, with little regard for what is fair, and responding to their own interests and personal risk of a catastrophic climate event. However this may have been different if we had allowed our players to communicate before the game.

The climate change game is a threshold public goods game, and as such there are near infinite Nash equilibria, whereby given a cumulative set of contributions that sum to the required threshold, no one player can benefit by deviating from their spending (Nash 1950). Precise, quantifiable, within treatment, predictions are therefore difficult, although we can predict the rational limit for any particular player given his/her resources and level of risk (Tables 1 and 2) and that players will spend more when they face greater risks. However, as mentioned above, the game can also be conceptualized as a volunteer's dilemma (VOD), in which case one can predict that asymmetries will lead to the 'strong' being exploited (Diekmann 1985, 1993), perhaps in a form of 'brinkmanship' by those with less to lose not cooperating (Archetti 2009; Schelling 1960). This prediction is borne out in the greater proportional spending by the rich players in the unequal-wealth (but equal risks) treatment. In this way, asymmetries can also potentially increase coordination in volunteer dilemmas, despite the competing fairness norms introduced by such asymmetries (see above). Of course the strong players in our game are not always so identifiable, as both resources, and increasing risk, lead to greater self-interest in avoiding climate change. The rich-suffer treatment brings these two features together, making group success more likely, whereas the poor-suffer treatment pulls them apart, reducing the chances of group success.

Alternatively, if one takes a group level perspective, one can use the expected collective damage to predict the outcomes, as the poor-suffer treatment had the least to lose and the rich-suffer treatment the most (Tables 1 and 2) (Croson and Marks 2000). This is a result of there being more poor than rich players, and thus the mean level of risk is not simply intermediate between the two extremes but rather a weighted average. Of course the players may not be aware nor responding to the group-level consequences, but their individual responses may sum to a predictable group performance (Charness and Sutter 2012). Further investigation of the individual behaviour will require experiments that hold the level of risk for focal players constant while manipulating the risk level for others and vice versa. This will address if players are responding more to their personal risks or to their potentially revised estimates about the likely contributions of others.

4.2 Comparison with other studies

Two other recent studies have also addressed the effect of endowment heterogeneity in climate games, but in different ways, such that they did not examine wealth and risk inequality as we have done (Milinski et al. 2011; Tavoni et al. 2011). Tavoni et al. (2011) created 'rich' and 'poor' players within groups not through different sized endowments, but through automatically controlling the spending of the players in the early phases of the game in order to create players that were poor because they had already contributed relatively more than others. They found that their rich players were willing to spend more. However, cooperation was more favourable for their rich than their poor in terms of expected payoffs so they would be predicted to spend relatively more out of self-interest. Regarding inequality, they found that only two of 10 unequal groups were successful compared to five of 10 equal groups, which suggests that inequality per se may have a detrimental effect. However when they also introduced communication, in the form of 'pledges' into their design, this detrimental effect was perhaps cancelled out by an enhanced ability for groups to coordinate their spending, as the success rate rose from two to six out of 10 unequal groups.

Interpretation of the results of Milinski et al. (2011) is slightly problematic because their experimental design does not directly test the effect of inequality. Specifically, the design confounded resource distribution with the total amount of resources. The design had rich groups, poor groups, and mixed groups (three rich members and three poor members), but did not adjust the required spending threshold accordingly. Consequently, the presence of rich members made it easier for the group to reach the target, analogous to reducing the investment required to avoid catastrophe. Not surprisingly the rich groups did best, as they had both a relatively easier task to achieve and more at stake to protect, and it is impossible to say if inequality per se had any effect. One can ask if the rich and poor players adjusted their spending depending on whether they were with alike or different players (although this is still confounded by the static target threshold). The answer is that the players did not make such adjustments, unless 'intermediate targets' were also introduced, suggesting that intermediate targets may facilitate cooperation between rich and poor. However, again interpretation is problematic, as the 'intermediate targets' not only eased the coordination problem, but also decreased the benefits of cheating (failure to reach such targets introduced additional costs), and thus two explanations for increased cooperation are confounded. Therefore it is not clear if intermediate targets alone would actually help or not.

A key aspect of our study is that whereas the above studies introduced different types of players ('rich' and 'poor') within groups, they still treated groups collectively, whereas we too have different types, but also allow different consequences for the different types. This is because global climate change will not necessarily have globally uniform consequences, either due to localized effects and disasters, or due to differing capabilities to withstand the consequences of climate change (Parry and Intergovernmental Panel on Climate Change. Working Group II 2007).

A possibly important omission from our experiment, and from previous studies, is the possibility for negotiation. We prevented all communication in order to be directly comparable to the results of Milinski et al. (2008), but it may be that negotiation would affect our results. How it would do this is unclear, but negotiation may allow for greater success via increased coordination. However increased awareness of the plans of others, via communication and non-binding pledges, opens the door to manipulative signaling and thus communication without enforcement is, theoretically at least, just cheap-talk and should eventually come to be ignored (Maynard Smith and Harper 2003).

Alternatively, there are two reasons why communication is not required in our experiment. This is because our experimental simulation is a simple model that (1) assumes all knowledge is certain and agreed (the threat and consequences are not debatable) so no communication is required to convince skeptics; and (2) all monitoring is reliable and immediate, so there is no need to convince others of one's own performance.

4.3 Relation to the real world

There are many differences between the real climate change scenario we face and the game our participants faced. Unfortunately, most of these differences are likely to lead to lower levels of cooperation (Raihani and Aitken 2011). For example, our participants: (1) had perfect information regarding the performances and targets of their group members; (2) directly incurred the costs and benefits of investing / not investing; (3) were directly responsible for their actions; (4) could expect larger or equal returns from the fully cooperative outcome compared to the fully selfish outcome; and (5) were playing in small groups. In contrast, the real world involves: (1) a lack of certainty regarding what steps are required and what steps others are taking; (2) immediate costs, but the benefits spread out over future generations; (3) governments enacting legislation that aims to influence the behaviour of others (Raihani and Aitken 2011); (4) potentially non-favourable returns from successfully cooperative outcomes over fully selfish outcomes (Eyckmans and Tulkens 2003; Nordhaus and Yang 1996); and (5) the interaction of many more agents than in our games, which creates weak participation incentives for a large fraction of emitters.

On the positive side, a feature of the real world that might lead to higher levels of cooperation than in our game is that contributions can be non-anonymous, which could provide 'status' that leads to other benefits (Milinski et al. 2006). Also, our sessions became more successful with more experience of the game (although this is a problematic interpretation as each group had had a different prior history). Whilst this result suggests that experience or knowledge can help prevent climate change, it is an unfortunate fact that we probably have to solve the real world climate game at the first attempt. Nonetheless, it may be that if people suffer some early shocks due to increasing climate change then these shocks may act to stimulate greater cooperation, providing that those with the power to enact change are sufficiently affected.

Finally, we also found a correlation between participants' reported real world beliefs and their in-game decisions, even though such beliefs were irrelevant to their potential payoffs (Fig. 4). This suggests we cannot even rely on people, selfish or otherwise, to act rationally—although it is also possible that the participants answered the questionnaire in a self-serving way, to justify their prior non-cooperative behaviour. Overall, our results suggest that we would be foolish to rely on a sense of altruism or even rational self-restraint if we hope to prevent damaging climate change. Both theoretical models and biological examples inform us that in such scenarios where individual self-restraint is not favored, a form of enforcement is required to stabilise cooperation (Bergmuller et al. 2007; Dutta and Radner 2004, 2009; Frank 2003; Ratnieks et al. 2006; Sachs et al. 2004; West et al. 2007).

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