Q Open, 2021, **1**, 1–16
DOI: 10.1093/qopen/qoab006
Advance access publication date: 30 April 2021
Article

Inequality hinders group efforts to avoid environmental disasters

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Received: September 30, 2020. **Accepted:** March 16, 2021

Abstract

Using a threshold public good experiment, we examine how varying degrees of inequality in resources and differences in risk of loss among players affect the success of group efforts to avoid a common loss. We find that when the poor face greater risk than the rich, contributions and success in reaching the threshold decrease with increasing inequality in funds available. This occurs not because the poor do not make a greater effort when they face higher risk but rather because the rich, who control most of the resources, tend to lower their contributions when they face the lower risk, and because a subset of the rich are not averse to inequality. These results highlight the challenges confronting parties in real-world situations, such as forest communities threatened by wildfire or countries confronting climate change, where group efforts are necessary if losses are to be avoided and the parties differ widely in available resources and in the risks they face.

Keywords: Climate change, Threshold public good, Environmental threat, Risk of loss, Burden sharing, Inequality, Experimental economics

JEL codes: Q54, H41, D31, C92, D81

1 Introduction

Human-caused environmental and ecological threats occur at various spatial scales, from local (e.g. wildfire threatening a rural forest community, excessive smog in a city) to regional (e.g. depletion of groundwater aquifers, natural habitat loss) to global (e.g. global warming, loss of rain forests). These threats are examples of social dilemmas, and their solution requires human cooperation. With social dilemmas, overall welfare of the entire group of agents is maximized if group members cooperate, but each individual member has an incentive to defect—to free ride in public-good situations or to fall victim to the Tragedy of the Commons in common-resource situations. Here we address the challenges that occur when group members differ in wealth and risk and find that the challenges increase with increasing disparity in wealth if, as is often the case, the poor face greater risk than the rich.

We examine these issues in the context of an additional complication that is common in natural resource problems—they are prone to tipping points. Beyond a certain level of impact, a resource might change dramatically and irreversibly. For example, a shift in Atlantic Ocean currents caused by global warming could irreversibly further alter the climate (Lenton *et al.*, 2019); saltwater intrusion into coastal freshwater aquifers may abruptly increase if aquifer withdrawal exceeds a point that is sensitive to sea level rise (Mazi *et al.*, 2013); and deforestation, droughts, and climate change might flip parts of the Amazonian rain forest into a savannah-like ecosystem with much less biodiversity (Amigo, 2020).

On the positive side, a tipping point provides additional motivation for human cooperation. If crossing a crucial tipping point results in disaster beyond the gradually increasing damage from, for example, additional harmful emissions of some kind, the group involved—on the local, regional, or global level—has a collective incentive to avoid crossing that tipping point. The tipping point can then serve as a coordination device and generate a second type of Nash equilibrium: contrary to the 'free-riding equilibrium' where nobody contributes to avoiding the problem, agents might contribute on aggregate just enough to avoid crossing the tipping point. Such a contribution pattern would be an equilibrium: if everybody else is 'doing their part' then a single individual has an incentive to 'do their part' as well since they become pivotal—the tipping point would be crossed if they did not also contribute (Barrett, 2016).

In groups with homogeneous users, who all have the same resources at their disposal and face the same (disastrous) consequences if the system moves beyond its tipping point, 'doing their part' is rather well defined and understood—the obvious focal point is for everyone to accept an equal share of the burden required to reach the threshold level of effort.[1] The issue becomes thornier in the more realistic case where group members differ in their available resources and/or suffer differently when the tipping point is surpassed.[2] Climate change is exemplary for both of these issues—unquestionably group members (countries in this case) are endowed with vastly different amounts of resources, and the risks from the effects of climate change differ markedly among countries and global regions (see, e.g., Kotchen, 2018).

How the burden of supporting a group is shared among unequal group members has long been a critical concern in international negotiations, such as in determining countries' contributions to NATO (Kravis and Davenport, 1963) or to climate change mitigation efforts (Page, 2008). Burden sharing is also an issue at much smaller scales such as in setting membership dues of a service club or local property tax rates, and is also a key element of efforts to limit use of common pool resources such as a shared groundwater aquifer (Madani and Dinar, 2012).

In essence, burden sharing involves deciding what is fair, and it can result in coordination failure. Unlike in market transactions, where an existing price provides a common reference point when considering the fairness of a price change (Kahneman *et al.*, 1986), a clear reference point is generally lacking in burden-sharing situations. With burden sharing, considerations of fairness tend to fall back on basic principles, most importantly ability to pay toward, and expected benefit from, the joint effort (Musgrave, 1959).

Complicating the determination of one's fair share is the fact that people have differing attitudes about inequality (Weinzierl, 2017; Bechtel *et al.*, 2018)—while some view it as a problem to be addressed, others see it as a natural condition needing no intervention. The former attitude has been called inequality aversion, as first coined by Fehr and Schmidt (1999); the later can be called inequality neutrality. Not only does the total contribution from a group depend in part of the mix of attitudes about inequality among the players, but individual contribution decisions also may reflect the player's impression of what others in the group are likely to contribute and how their contributions reflect their own attitudes about inequality.

[1] In what follows, we use the term 'tipping point' to refer to the natural system's negative change, while we use 'threshold' to refer to the cooperation level needed to avoid the system moving beyond its tipping point. We will call the type of equilibrium that results in aggregate contributions reaching the threshold a 'threshold equilibrium'.

[2] An additional complication—an uncertain tipping point or threshold—has previously been discussed in the literature; see, for example, Barrett and Dannenberg (2012) or Brown and Kroll (2017). In this paper, we assume certainty about the threshold needed to avoid a disaster.

The effects of inequality on willingness to contribute to joint efforts, and the way inequality affects burden sharing, have over the past four decades or so been studied in experimental settings (Zelmer, 2003; Ostrom, 2006). Incentivized experiments, where subjects have real money at stake, can zero in on key elements of the contribution question (Falk and Heckman, 2009), providing a clear starting point for understanding the effect of inequality on human decision making.

Effects of inequality in endowments on group behavior in incentivized experiments were first studied in linear public-good games, where the only equilibrium predicts that everyone free rides. Here agents who are inclined to contribute beyond their equilibrium levels might be uncertain about what constitutes a fair or reasonable contribution, which can have negative consequences for the total amount contributed and thus the overall size of the public good, as documented in lab experiments by, for example, Anderson *et al.* (2008), Cherry *et al.* (2005), and Hargreaves Heap *et al.* (2016).

In public-good games with a threshold equilibrium in addition to the free-riding equilibrium, inequality weakens the function of the threshold as a coordination device. Agents might recognize that the group is better off if it reaches the threshold AND that it would be in everybody's individual interest to contribute enough to make up any difference between the current total group contribution and the threshold amount, if possible. However, opinions are likely to vary on how the burden of making it to the threshold should be shared among unequal group members.

Threshold public-good experiments have been reported since the early 1990s; for early examples, see Bagnoli and McKee (1991) or Rapoport and Suleiman (1993). One type of threshold public good game, motivated principally by concerns about climate change, focuses on probabilistic losses if subjects fail to contribute enough to reach a threshold (Blanco and Walker, 2019), and has been called the 'collective risk social dilemma' (Milinski *et al.*, 2008). In this game subjects can avoid a possible catastrophe if as a group they contribute enough of their funds to reach the threshold. If the threshold is not reached, their contributions do nothing to lessen the disaster risk and subjects each face a known probability of losing all their remaining funds. This setup is intended to represent situations like that of countries attempting to avoid a 2°C global temperature increase, as called for in the Paris Agreement of the United Nations Framework Convention on Climate Change, or users of a groundwater aquifer attempting to avoid a level of total use that would unalterably compromise the aquifer (Maas *et al.*, 2017). As in other social dilemmas, individual players have an incentive to limit their contributions (i.e. to free-ride) if they think others will contribute enough for the group to reach the threshold, but not to limit them so much that the group just misses the threshold, for all of the players may in expectation be better off if the threshold is reached and the threat of loss is prevented.

Most early threshold public-good experiments endowed all subjects in a group with the same amount of funds to use in the experiment, but since the early 2000s such experiments have increasingly been used to learn about the effects of inequality in endowments on group efforts (Blanco and Walker, 2019). Two basic questions addressed in such studies are (1) how does the introduction of inequality affect total contribution to the group account and success of the group in providing the public good (e.g. reaching the threshold and avoiding a common loss), and (2) how is the burden of providing the public good shared when group members differ in their resources (e.g. endowments) or in the benefits they would receive from the public good (e.g. the risk of loss they would avoid)?

Regarding the first question, the effect of introducing inequality of endowment in threshold public good studies has been minimal, with little difference between equal and unequal endowment groups in the overall proportion of endowment contributed (Table A1 and Fig. A1 in the Supplementary material). Our results are consistent with this general finding; we found only a small overall effect of introducing inequality in endowments when the risks were equal. We observe a strong effect, however, when the less-advantaged face a higher risk.

On the second question, burden sharing within unequal endowment groups has varied widely across threshold public good studies of groups presented with the opportunity to avoid a loss (Table A2 in the Supplementary material). Among the eight such studies with treatments having relatively rich and poor subjects face the same risk of loss, four observe the poor contributing a substantially greater percentage of endowment than the rich (Milinski *et al.*, 2011; Brekke *et al.*, 2017; Español, 2018; Vicens *et al.*, 2018), two show the opposite (Burton-Chellew *et al.*, 2013; Gampfer, 2014), and the remaining two (Brown and Kroll, 2017; Waichman *et al.*, 2018) found little difference between the two groups (Fig. A2 in the Supplementary material). We expect that methodological differences are the cause of the varying results across studies.

The main contribution of our paper is to systematically examine the impact of different levels of income inequality on joint efforts to reach a threshold level of contribution in order to avoid the risk of a common loss. Among the nine threshold public-good studies to avoid a loss we found that implemented unequal endowments, all used just one set of unequal endowments (Table A2 in the Supplementary material). Comparing across the full set of studies would offer a picture of how changing the within-group degree of inequality affects contributions toward the public good, but because the individual studies differ from each other in many ways, direct comparisons across them—to see, for example, how burden sharing varies with level of inequality—are problematic, as no two treatments differed only in amount of inequality among endowments in the group. We aim to bring some clarity to that issue. In our study, subjects each encounter various levels of inequality, including a condition where the rich have endowments over six times those of the poor, allowing us to map out how contributions change as inequality becomes more extreme, and to observe how the changes in contributions affect group success in reaching the threshold.

In addition to differing in endowment, parties confronted with a common loss in real-life situations rarely face equal risks of loss if the joint effort fails. For example, countries face different risks of flooding disasters caused by climate change, communities located within a forest likely are exposed to different risks of wildfire-related catastrophes, and individual farmers relying on the same aquifer for irrigation water encounter different risks depending on where they are located relative to the underlying cones of depression. Recent experiments of joint efforts to avoid losses, in addition to studying the effect of unequal endowments, have examined the effect of unequal risks of loss on contributions to the joint effort. Three studies compared an equal risk treatment with one where the poor faced a greater risk of loss than the rich (Table A2 in the Supplementary material). Two of those studies (Burton-Chellew *et al.*, 2013; Gampfer, 2014) found that risk made a significant difference; when the poor faced greater risk, they increased their contributions and the rich lowered theirs, compared with an equal risk treatment. However, Waichman *et al.* (2018) found that shifting the risk to the poor had little effect on contributions of rich or poor subjects (Table A2 in the Supplementary material). Burton-Chellew *et al.* also included a treatment where the rich faced greater risk and found that the rich increased their contributions and the poor lowered theirs, compared with the equal risk treatment (Table A2 in the Supplementary material). Our secondary objective in this paper is to observe how differences in relative risk affect burden sharing at the levels of inequality we examine.

We find that an increase in inequality of endowments tends to lower group total contribution and success in reaching the threshold, but that the drop is only pronounced when the poor face a greater risk of loss than the rich do. This occurs because of the combination of two factors. First, relative risk affects contributions: those at higher risk contribute a higher percentage of endowment than those at lower risk. Second, the rich control most of the resources, especially at high levels of inequality, so they largely control the possibility of the group reaching the threshold. Thus, the poor can be increasingly left in the lurch when they face the greater risk. However, this does not happen with all groups. Individuals, and the groups they form, differ in their willingness to contribute to group success. About half

Table 1. Experimental sessions.

Session	Information[a]	Groups	Subjects	Responses
1	No	4	16	480
2	Yes	5	20	600
3	No	4	16	480
4	Yes	5	20	600
5	No	5	20	600
6	Yes	3	12	360
7	Yes	5	20	600
8	No	4	16	480
9	Yes	5	20	600
10	No	5	20	600
Total		45	180	5,400

[a]Results from the 'yes' sessions are presented in Appendix C (Supplementary material).

of the groups in our study reached the threshold. In groups that were successful in reaching the threshold, success happened because the rich in those groups tended to increase their percentage contribution as they became richer, despite the poor decreasing theirs as they became poorer. In unsuccessful groups, however, the rich tended to decrease their percentage contribution as they became richer. As inequality increases, much depends on the rich, who do not necessarily cooperate.

2 Experimental design

2.1 Procedures

The experiment consisted of 10 sessions, with three to five groups of four subjects in each session, for a total of 180 subjects arranged in 45 groups (Table 1). Each subject was seated at a computer terminal and responded to questions presented on his or her computer screen using Z-tree (Fischbacher, 2007). A session consisted of instructions and practice periods and then 30 independent and potentially binding periods. Subjects were randomly reassigned to groups at the beginning of each period and did not know who else in the room was in their group (stranger design). Subjects did not communicate with each other.

In each of the 30 periods, subjects were given an endowment of tokens and then asked how many tokens they would contribute to a group account. They knew that if the total contribution from the four subjects in their group was less than 100 tokens they risked losing their remaining tokens in that period, but if the 100-token threshold was reached they faced no such risk. As is not uncommon in threshold public good experiments (e.g. Milinski *et al.*, 2008; Burton-Chellew *et al.*, 2013), the threshold was known with certainty. Avoiding ambiguity about the threshold allowed us to focus more clearly on treatment effects of most interest here. After completion of all thirty periods, five periods were randomly selected as binding and used to determine each subject's payout. At the end of the experiment tokens were exchanged for US$ at an exchange rate of five tokens per dollar. Note that in our experiment an outcome is reached in each period, unlike in typical collective risk social dilemma games (e.g. Milinski *et al.*, 2008; Burton-Chellew *et al.*, 2013; Brown and Kroll, 2017) where the outcome is determined only after 10 consecutive periods. Since we were not interested in the dynamics of the interactions we chose to use a one-period set-up in order to generate a richer data set, similar to, for example, Brekke *et al.* (2017) and Rapoport and Suleiman (1993).

At the beginning of a session, subjects were randomly assigned to be of type A or type B. Subjects maintained their type throughout the session. In each period, there were two type-A subjects and two type-B subjects in each group. A subject's type defined the endowment

Table 2. Endowment combinations and ratios (rich/poor).

	Endowment		
	Rich	Poor	Ratio
1	50	50	1
2	67	33	2
3	75	25	3
4	80	20	4
5	86	14	6.1

with which the subject began each period. The sum of the endowments of the four subjects in a group was always 200, but the endowments of the two different subject types usually differed. The following five endowment combinations were used: (1) type-A subjects with 50 tokens and type-B subjects with 50 tokens; (2) A 67, B 33; (3) A 75, B 25; (4) A 80, B 20; and (5) A 86, B 14. The five different endowment conditions implement five levels of relative wealth (endowment ratio, Table 2). No prior study has implemented as many different levels of relative wealth, or such a high ratio as 6. In what follows we refer to type-A subjects as 'rich' and type-B subjects as 'poor,' although when the endowment combination is 50/50 the rich/poor distinction is nondescriptive. The reason for keeping a subject's type fixed throughout the session was to maintain the subject's experience of being relatively well off or relatively poor.

To reach the threshold of 100 tokens, equal proportions of endowment contributed by rich and poor are possible at all five endowment ratios, but equal absolute contributions are possible at only the first three endowment ratios (where all four subjects contribute 25 tokens), and equal outcomes (i.e. endowment minus contribution) are possible at only the first three endowment ratios (see Brekke *et al.*, 2017, for a discussion of the different burden sharing rules for reaching a threshold).

In addition to the endowment combination, the risk of loss was also varied across periods. The following three risk scenarios were used: (1) rich subjects face a 0.9 probability, and poor subjects face a 0.5 probability, of losing their remaining tokens ('rich suffer more'); (2) rich 0.5, poor 0.9 ('poor suffer more'); and (3) rich 0.7, poor 0.7 ('equal risk'). At the beginning of each period, subjects could see the endowment levels and risk of all four group members.

Each endowment combination was crossed with each risk scenario, resulting in 15 different conditions. Using a within-subject design, wherein each subject encounters all treatment combinations, allowed for efficiently implementing the 15 different conditions, provided for enhanced statistical power compared with a between-subjects design, and allowed us to observe the extent to which individual participants clearly distinguish among alternative wealth distributions and risks. A potential downside of a within-subject design is that subjects will obtain information from the outcome of earlier periods and use that information in responding in later periods/treatments, and thus that the periods will not be independent observations of subject contribution. We aimed to avoid that downside by, in the five 'no' information sessions (Table 1), providing no feedback on what other subjects had contributed and thus on how well the group did in reaching the threshold. With no information on the outcome of subjects' contributions in any of the periods, we expected that independence among periods, and thus across treatments, would be maintained over the course of the experiment. The stranger design, mentioned above, was also chosen to enable independence. The 'no' information sessions provide the main data of our experiment.

We included the five additional 'yes' information sessions (Table 1), where subjects could see the amounts contributed by each of their previous group's members, in order to check whether our results also held when subjects had information about what happened in their groups in previous periods, since it is well-known in the experimental literature that subjects in their decision-making may be impacted by behavior of other group members and outcomes in previous periods (e.g. Kroll and Shafran, 2018). Because the results of the 'yes' information sessions do not alter our main conclusions, those results are presented in Appendix C (Supplementary material).

In the first session we conducted, the 15 conditions were presented in random order, one per period, and then presented again in a different random order for a total of 30 periods. To avoid order effects, that same random order of the 30 periods was used in all subsequent sessions. This use of a 'pseudo-random feed' has been standard in lab experiments with random effects; see, for example, Cox *et al.* (2001) or Kroll and Shafran (2018).

With 45 groups of four subjects each responding in each of 30 periods, we have 1,350 measures of group contribution and 5,400 individual contribution amounts, of which 660 group total contributions and 2,640 individual contributions occurred in the 'no' information condition. Because of a programming mistake, 15 of the 120 group responses in the first session were not usable, leaving for analysis 645 group contributions and 2580 individual contributions in the 'no' information condition.

Regression analyses were performed using the GLIMMIX procedure in SAS 9.4. GLIMMIX handles estimation and statistical inference for generalized linear mixed models; thus, the procedure allows for random effects and nonnormal response data. In our models, Session (Table 1) was included as a random variable. A Gaussian, beta, or binary response distribution was specified, depending on the response variable of the particular regression, as indicated later on. Most two-way interactions were included in the regressions.

Subjects were recruited in freshman- and sophomore-level general education classes containing students with a wide variety of majors. No specific information about the experiment was provided during recruiting, except that subjects could earn money. The experiment had an approved IRB protocol, and complied with all relevant ethical regulations. See Appendix B (Supplementary material) for the experimental script.

2.2 Expectations

In each period of our experiment, subjects in groups of four each decide how much of their endowment to contribute to a group account. Subjects know that if the sum of their contributions to the group account, C, does not reach the threshold, T, they will face a probability p_i of losing all their remaining funds. With c_i as player i 's contribution to the public good, e_i as the player's endowment, and p_i as the player's risk of loss, player i 's payoff is $e_i - c_i$ if $C \geq T$, and expected payoff is $(1 - p_i)\ (e_i - c_i)$ if $C < T$. In all periods, the sum of the four endowments is fixed at $E = 2T$. In most periods two players have a higher endowment than the other two players.

As usual in threshold public-good games of this kind, there are many Nash equilibria. One Nash equilibrium is, as in standard summation public-good games without a threshold, for every subject to contribute 0, because unless the group contributions are sufficient to reach the threshold any individual contribution lowers the subject's expected payoff.

A second kind of Nash equilibrium exists in which $C = T$. Assuming that subjects are risk neutral and unaffected by endowment inequality (which we will call being 'inequality neutral'), with $p_i = 0.5$, subject i is indifferent between no contribution and a potential 'disaster' ($c_i = 0$ and $C < T$), and contributing half of their endowments when the potential disaster is avoided ($c_i = e_i/2$ and $C \geq T$); in both cases subject i ends up with a (expected) payoff of $0.5 \bullet e_i$. For $p_i > 0.5$, subject i prefers any $c_i < p_i \bullet e_i$ if $C \geq T$ to $c_i = 0$ if $C < T$. Other equilibria apply with non-neutral risk or inequality preferences. For example, if subjects are risk averse and inequality neutral, if $p_i = 0.5$ subject i will prefer $c_i = e_i/2$ if $C \geq T$ to $c_i = 0$ if $C < T$. And if $p_i > 0.5$ the risk averse subject will be willing to contribute even more than when $p_i = 0.5$. It follows that if some subjects in a group face a $p_i = 0.5$ and others face a $p_i > 0.5$, the later subjects are willing to contribute more than the former ones.

If subjects are not inequality neutral (but are risk neutral) and $p_i = 0.5$, the indifference between $c_i = 0$ if $C < T$ and $c_i = e_i/2$ if $C \geq T$, given above for inequality neutral subjects, may be lost. When subjects are attempting to reach the threshold, one possibility, suggested by Bechtel *et al.* (2018), is that poor subjects would be unhappy contributing the same proportion of endowment as the rich and rather would opt for some $c_i < e_i/2$, and rich subjects would feel a responsibility to contribute more than $e_i/2$, all else equal; in these cases they each could be said to exhibit inequality aversion. Of course, the rich may not feel such a responsibility, and may remain inequality neutral (contributing $e_i/2$ at all endowment levels) or even decrease their contribution percentage as their endowment increases while the poor remain inequality averse, resulting in $C < T$. Other possibilities are also feasible.

Two outcomes of our experiment are highly likely. First, based on results of earlier research (Fig. A1 in the Supplementary material), no overall effect of inequality in endowment on group total contribution is expected when risks are the same for all subjects. Second, also in line with past findings, risk of loss will affect contributions, raising them from those facing the higher risk and lowering them from those facing the lower risk, relative to equal-risk contributions. Given that the rich have higher endowments than the poor, we therefore expect that group total contributions (hereafter just 'group contribution') will be lowest when the poor face a larger risk than the rich. However, we cannot make firm predictions about the effects of the experimental treatments on burden sharing. As mentioned above, prior studies present conflicting results on burden sharing. Further, we do not know the inequality preferences of the subject population. Thus, we have no clear expectation on the effect of unequal endowments on the relative proportions of endowment contributed by rich and poor subjects, or on how burden sharing will change as inequality of endowment changes over the range being examined. Indeed, our primary goal is to map out the relation of inequality to burden sharing, and thus offer a first clear look at the joint effects of inequality in endowment and risk on individual and group contributions over a range endowment inequality.

3 Results

We express inequality as the ratio of endowments (rich/poor). Our main results, presented below, are based on the five 'no' information sessions. Our most fundamental finding from those sessions is that the effect of inequality on group contributions and success depends on how the risk of loss is distributed among the group members. If the poor suffer more (i.e. face a higher risk) than the rich, joint efforts to avoid common losses are less successful. Furthermore, if the poor suffer more, success becomes more difficult as inequality among the players increases, in contrast to if the rich suffer more or if the risks are equal, where increasing inequality has relatively little effect on group contributions and success. In the following three sections we report on (1) group success in reaching the threshold, (2) subject-level contributions, and (3) burden sharing. The effects of differing risks of loss are addressed in each section. Results on the effect of information about the contributions of others and the change in contributions over the course of the 30 periods of the experiment are presented in Appendix C (Supplementary material). See Appendix D (Supplementary material) for contribution means and standard deviations by major experimental condition.

3.1 Success in reaching the threshold

Across the 645 group opportunities of 'no' information sessions, 44 per cent of the groups contributed at least 100 tokens to the group account. That over one-half of the groups failed

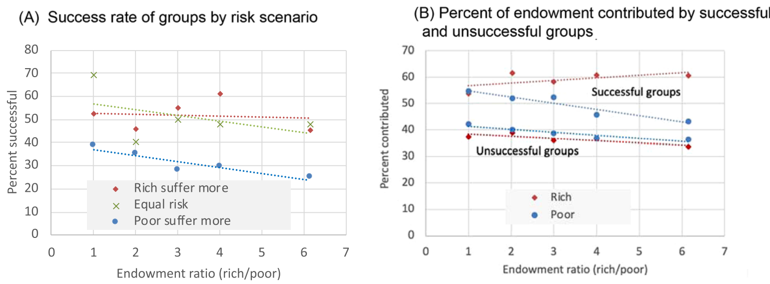

Figure 1. Success in reaching the threshold (total contribution ≥ 100) at five endowment ratios.

Table 3. Regressions on group success[a], with group-level results as cases ($n = 645$).

Effect[b]	Coefficient (standard error)
Intercept	0.5274 (0.4759)
EndowRatio	−0.1094 (0.0792)
RiskScenario (poor suffer more)	−0.8256* (0.4354)
RiskScenario (rich suffer more)	−0.2856 (0.423)
Period	−0.0104 (0.0098)
EndowRatio • RiskScenario (poor suffer more)	−0.0264 (0.12)
EndowRatio • RiskScenario (rich suffer more)	0.08861 (0.1129)

*, **, and *** indicate significance at the 10 per cent, 5 per cent, and 1 per cent levels, respectively. Standard error in parentheses.

[a]Success is modeled on a binary response distribution.

[b]Endowment ratio (EndowRatio, Table 2) and Period as continuous variables, all others as class variables.

to reach the threshold is notable in light of the lost returns if the threshold was not reached: if successful the rich and poor subjects on average earned 29 and 14 tokens, respectively, but if unsuccessful they earned 16 and 5 tokens, respectively.

Group success was lower when the poor suffered more (31 per cent) than when risks were equal (51 per cent) or when the rich suffered more (52 per cent) (Fig. 1A); these differences are supported in the regression on success rate, where variable RiskScenario is negative and significant, $p = 0.058$, when the poor suffer more but not significant when the rich suffer more (Table 3).

At any given endowment ratio, contributions from both rich and poor were substantially higher in successful groups than unsuccessful groups (Fig. 1B). Given equal endowments, for example, in successful groups both rich and poor contributed on average about 55 per cent of their endowments, whereas in unsuccessful groups they both contributed on average about 40 per cent of their endowments.

As endowment inequality increases, success increasingly depends on the behavior of the rich, who progressively control more of the resources. Among successful groups the rich maintained a high level of contribution (about 60 per cent of endowment) at all endowment ratios >1, whereas the poor continuously decreased the per cent of endowment that they contributed as endowment inequality increased (Fig. 1B). In contrast to successful groups, among unsuccessful groups the rich contributed strikingly less and contributed a

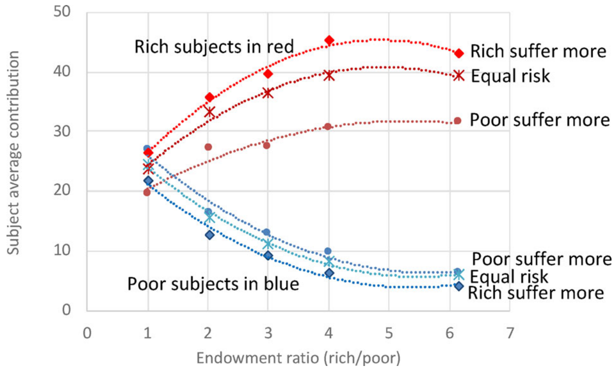

Figure 2. Subject average contributions by endowment ratio and risk scenario (based on data from successful and unsuccessful groups).

successively lower percentage of their endowment as endowment inequality increased. For example, at an endowment of 50 tokens the rich contributed an average of 54 per cent in successful groups and only 37 per cent in unsuccessful groups, and with an endowment of 86 tokens they contributed an average of 61 per cent in successful groups and only 34 per cent in unsuccessful groups (Fig. 1B). The poor, however, continuously decreased their percentage contribution as inequality increased, in line with their behavior in successful groups (Fig. 1B).

3.2 Subject contributions as inequality becomes more extreme

Looking now at subject-level contributions, we can further compare the actions of rich and poor subjects (Fig. 2). When all four subjects shared the same endowment (endowment ratio = 1) and risk of loss (0.7), they on average contributed the same amount (24 tokens). However, when endowments or risks differed, so did contributions. And, as would be expected, at all endowment ratios >1 the rich contributed more than the poor (in the Amount regression, Wealth is positive and significant, Table 4).

Two findings shown in Fig. 2 are of particular interest. First, as their endowment increased the rich on average consistently contributed more in absolute terms than the poor. This is supported by the positive and significant EndowRatio•Wealth interaction for the rich in the Amount regression (Table 4). Similarly, as their endowment decreased the poor on average consistently contributed less (Fig. 2). Second, individual contributions of both rich and poor subjects reflect the relative risks being faced; subjects contributed more when they rather than others faced the greater risk (Fig. 2). Importantly, the rich contributed substantially less when the poor suffered more than when they themselves suffered more or when the risks were equal (Fig. 2). This finding is supported in the Amount regression, where the RiskScenario•Wealth interaction is negative and significant for the rich when the poor suffer more, and positive and significant for the rich when they suffer more, compared with when the risks are equal (Table 4).

3.3 Burden sharing

We assess burden sharing in terms of the percentage of endowment that the rich and poor contribute to the group account. Across all risk scenarios combined (Fig. 3A), as endowments diverge (i.e. as endowment ratio increases) the percentage of endowment contributed drops; this is confirmed in the regression on subject proportion contributed, where the coefficient on EndowRatio is negative and significant (Table 4). However, the drop is more pronounced for the poor than the rich (Fig. 3A), as supported in the regression on subject

Table 4. Regressions on subject contribution amount and proportion of endowment contributed ($n = 2580$).

Effect[a]	Amount[b]	Proportion[c]
Intercept	24.1553***	0.08519
	(1.6195)	(0.1467)
EndowRatio	−3.2049***	−0.06708***
	(0.2665)	(0.01895)
Wealth (rich)	2.5308**	−0.06262
	(1.2207)	(0.08667)
RiskScenario (poor suffer more)	3.2736**	0.2261**
	(1.3614)	(0.09639)
RiskScenario (rich suffer more)	−3.4089**	−0.3046***
	(1.3589)	(0.09654)
Period	−0.04398	−0.00515***
	(0.02789)	(0.00198)
EndowRatio • RiskScenario (poor suffer more)	−0.508	−0.00757
	(0.3318)	(0.02361)
EndowRatio • RiskScenario (rich suffer more)	0.288	−0.0273
	(0.3282)	(0.02349)
EndowRatio • Wealth (rich)	5.7698***	0.05706***
	(0.2704)	(0.01936)
RiskScenario (poor suffer more) • Wealth (rich)	−9.1488***	−0.6193***
	(1.1735)	(0.08335)
RiskScenario (rich suffer more) • Wealth (rich)	6.117***	0.5885***
	(1.1718)	(0.08357)

*, **, and *** indicate significance at the 10 per cent, 5 per cent, and 1 per cent levels, respectively. Coefficients listed with standard errors in parentheses.

[a]Endowment ratio (EndowRatio, Table 2) and Period as continuous variables, all others as class variables.

[b]Gaussian response distribution.

[c]Beta response distribution, with proportions of 0 and 1 converted to slightly larger and smaller proportions, respectively. Because the logit transformation is used for the regression, the values presented are in terms of the log of the odds ratio.

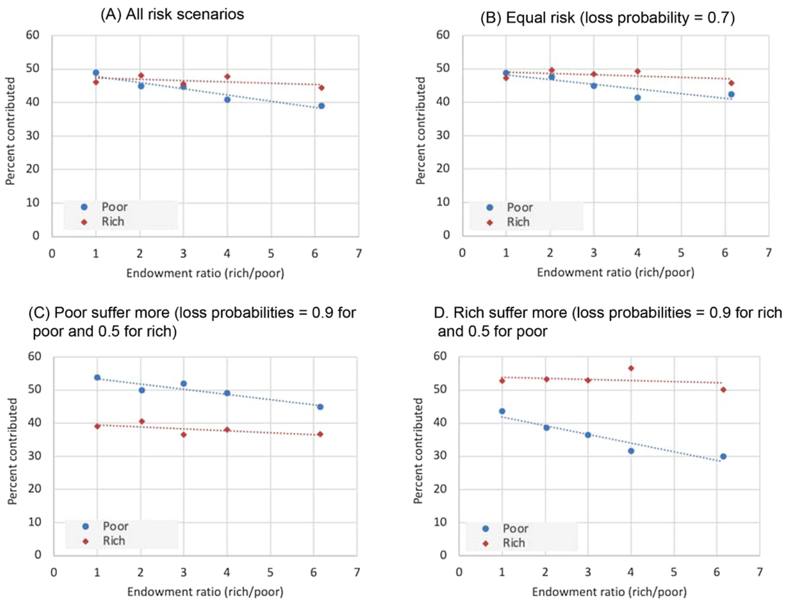

Figure 3. Percent of endowment contributed as affected by inequality and relative risk of loss scenario (based on data from successful and unsuccessful groups).

proportion contributed, where the EndowRatio•Wealth (rich) interaction is positive and significant (Table 4). That is, increasing endowment inequality is affecting the poor much more than it is the rich.

Interestingly, the results shown in Fig. 3A differ depending on whether the group was successful or not in reaching the threshold. Among unsuccessful groups (Fig. 1B) the proportions contributed by rich and poor subjects are nearly identical at all endowment ratios, dropping from about 40 per cent to 35 per cent as endowment ratio increases from 1 to 6. In contrast, among successful groups rich and poor subjects increasingly diverge in proportion contributed as endowment inequality increases, the proportion from poor subjects dropping to about 43 per cent at the highest endowment ratio while the proportion from the rich remains around 60 per cent at all positive endowment ratios (Fig. 1B). Unfortunately, our data do not support determining the reason for the striking similarity in proportion contributed between rich and poor subjects among unsuccessful groups.

Looking at burden sharing separately by risk scenario shows that relative risk significantly affects how the costs are shared. When the risks of loss were equal, rich and poor subjects contributed at similar levels, although the rich contributed a slightly higher percentage of endowment than the poor (Fig. 3B); on average across the five endowment combinations, the rich and poor contributed 48 per cent and 45 per cent, respectively. The finding that the rich tended to contribute a higher percentage of endowment than the poor when the risks were equal is contrary to findings in some other threshold public good experiments (Fig. A2 in the Supplementary material) as well as in some non-threshold public good experiments (e.g. Cardenas *et al*., 2002; Keser *et al*., 2017).

A different story emerges when the risks differ (Fig. 3C and D). Those facing greater risk generally contributed a substantially greater proportion of their endowment than those facing the lesser risk; this is confirmed in the proportion regression, where the RiskScenario•Wealth interaction is negative and significant for the rich if the poor suffer more and positive and significant for the rich if the rich suffer more (Table 4). Across the five endowment ratios, those facing the greater risk contributed from 55 per cent to 46 per cent of their endowments, whereas those facing the lower risk contributed from 43 per cent to 31 per cent, with the percentage falling for both rich and poor as inequality increased, and falling more steeply for the poor than the rich (this difference in slope is supported by the positive and significant EndowRatio•Wealth interaction for the rich in the proportion regression, Table 4). (See Appendix E in the Supplementary material for detail on an exception to this general finding: when the poor faced the greater risk and the group was successful in reaching the threshold, the contribution proportions of rich and poor were similar.)

4 Discussion and conclusions

Our experimental results show that both burden-sharing principles mentioned in Section 1—ability to pay toward the group effort (i.e. wealth) and benefit received if it is funded (i.e. loss prevented)—play key roles in people's response to inequality. On average, those better able to pay were willing to pay more, and those who would receive the greater benefit tended to pay more than they otherwise would. Combined with the fact that when endowments differ widely the rich control most of the resources and largely determine the success of the group's efforts, these principles chiefly explain the results. Importantly, when the poor faced the larger risk of loss, the likelihood of success in reaching the threshold was low even when endowments were equal and dropped further as inequality increased (Fig. 1A). Clearly, success is difficult when the poor are most at risk.

However, those principles do not provide a full explanation of our experimental results, as two additional factors played a role. First, as endowment inequality increased and their endowment decreased, the poor decreased the percentage of their endowment that they contributed to the group account, leading to a general decrease in percentage contribution to the group account as inequality increased. As the poor became poorer it is not surprising that they decreased their contribution percentage, since otherwise the amount that they got to keep became very small in absolute terms. Comments provided at the end of the experiment indicated that some of the poor were thinking that as they became poorer and the rich correspondingly became richer the rich should step up and help—as would occur, for example, if a progressive taxation scheme were imposed. Interestingly, on average the rich did not follow along. Rather than increase their percentage as they became richer, the rich on average maintained (or slightly lowered) their contribution percentage, demonstrating that on average the rich were not inequality averse.

Second, rich as well as poor subjects varied widely in willingness to contribute, ranging from those willing to contribute very little to those consistently contributing over one-half of their endowments. As Fehr and Schmidt (1999) posited in their classic paper on fairness in competitive situations, and in line with other recent experimental findings (Ballard-Rosa *et al*., 2017; Weinzierl, 2017; Bechtel *et al*., 2018), we found that people differ in willingness to contribute to a group effort as well as in acceptance of endowment inequality and their willingness to ameliorate it. Thus, as inequality increases and the rich become more essential to group success, they vary in their willingness to help the group reach the threshold and protect the wealth of group members. In our experiment nearly one-half of the groups reached the threshold and in those groups most of the rich did not decrease their percentage contribution as they became richer, even as the poor decreased their percentage contribution as they became poorer. In contrast, when groups did not reach the threshold, the rich on average contributed substantially less than half of their endowment and decreased their percentage contribution as they became richer. Furthermore, lack of success occurred most often when the poor faced the greater risk of loss (in this case only about 30 per cent of groups reached the threshold), largely due to the fall in contributions from the rich, showing that (as in Burton-Chellew *et al*., 2013) when others are facing a higher risk the rich are generally less willing to contribute. With the likelihood of success being largely dependent on a subset of players (the rich in this case), success can be illusive.

These results have implications for environmental resources at a wide range of spatial scales, from global to local. At the global scale, the results are consistent with the current consternation about international climate change mitigation negotiations, which are impacted by both of the inequalities we examine. The parties, in this case countries, differ greatly in wealth. Just among EU countries the richest has a GDP per capita about 15 times that of the poorest; among the full set of the world's countries this ratio rises to over 300. Further, although no country will be unaffected, some face much greater threats than others. For example, some low-lying countries with relatively long coastlines, such as some island nations, face great risks of wholesale coastal flooding, while others face little such threat. And temperature increases will, all else equal, hurt equatorial countries more than those with more moderate climates. As our research, and that of others, indicates, these differences in wealth and risk greatly complicate the job of agreeing on an equitable sharing of the mitigation burden. Furthermore, countries also differ in culture and political system, and such differences affect the perception of what constitutes a fair or reasonable burden-sharing rule and thus the willingness and ability to collectively respond to global threats. Combined with the inherent difficulties of protecting a common pool resource when enjoyed by a large number of users, it is no surprise that international climate negotiations have so far achieved little.

In contrast to the global scale, at the local scale the actors are likely to be individuals, households, or small firms, such as irrigated farms drawing from a groundwater aquifer, landowners exploiting a habitat critical to a threatened species, and rural homeowners facing the possibility of devastating wildfire. In each case a tipping point may be reached beyond which catastrophe is unavoidable. And while the differences here are not as pronounced as in the global climate change case, the actors still differ in size and wealth, as well as in risk of loss if a tipping point is breached. Our research suggests that the greater is the inequality among the actors, the lower is the likelihood that they will band together and agree to limit use or implement recommended practices in order to avoid reaching the tipping point, and that the likelihood is particularly low if the more well-off face the lower risk.

However, we are talking of challenges here, not foregone conclusions. As the challenge rises, so does the need for concerted effort. Because typically the general welfare is improved if the tipping point is not reached, what is needed is a general understanding that the threats are real and an agreement about how the burden is to be shared. Our results suggest that it is most importantly the uncooperative rich who must be persuaded of the benefit of helping to protect the group. A key question for further research is thus: why do some rich subjects lower their percentage contribution at high levels of inequality? Are they limited by fear of being suckered, hamstrung by uncertainty about what their fair share is, underestimating what others will contribute, or somehow otherwise constrained? Understanding the reasons for the declining willingness to contribute at higher levels of inequality is the first step toward interrupting such tendencies on the part of the less cooperative rich.

Supplementary material

Appendices are available at *QOPEN* online.

Funding

Funding was provided by the Rocky Mountain Research Station. Kroll acknowledges support from the Colorado Agricultural Experiment Station.

Conflict of interest

The authors declare that they have no conflicts of interest.

References

Amigo I. (2020) 'When will the amazon hit a tipping point?', *Nature,* 578: 505–7.

Anderson L. R., Mellor J. M. and Milyo J. (2008) 'Inequality and public good provision: an experimental analysis', *Journal of Socio-Economics,* 37: 1010–28.

Bagnoli M. and McKee M. (1991) 'Voluntary contribution games: efficient private provision of public goods', *Economic Inquiry,* XXIX: 351–66.

Ballard-Rosa C., Martin L. and Scheve K. (2017) 'The structure of American income tax policy preferences', *The Journal of Politics,* 79/1: 1–16.

Barrett S. (2016) 'Coordination vs. voluntarism and enforcement in sustaining international environmental cooperation', *Proceedings of the National Academy of Sciences,* 113/51: 14515–22.

Barrett S. and Dannenberg A. (2012) 'Climate negotiations under scientific uncertainty', *Proceedings of the National Academy of Sciences,* 109/43: 17372–6.

Bechtel M. M., Liesch R. and Scheve K. F. (2018) 'Inequality and redistribution behavior in a give-or-take game', *Proceedings of the National Academy of Sciences,* 115/14: 3611–6.

Blanco E. and Walker J. M. (2019) 'Common-Pool Resource Appropriation and Conservation: Lessons from Experimental Economics'. In: B., Hudson, J., Rosenbloom, and D., Cole (eds.) *Routledge Handbook of the Study of the Commons*, pp. 106–16. London, England: Routledge.

Brekke K. A., Konow J. and Nyborg K. (2017) 'Framing in a threshold public goods experiment with heterogeneous endowments', *Journal of Economic Behavior & Organization,* 138: 99–110.

Brown T. C. and Kroll S. (2017) 'Avoiding an uncertain catastrophe: climate change mitigation under risk and wealth heterogeneity', *Climatic Change,* 141/2: 155–66.

Burton-Chellew M. N., May R. M. and West S. A. (2013) 'Combined inequality in wealth and risk leads to disaster in the climate change game', *Climatic Change,* 120/4: 815–30.

Cardenas J. C., Stranlund J. and Willis C. (2002) 'Economic inequality and burden-sharing in the provision of local environmental quality', *Ecological Economics,* 40/3: 379–95.

Cherry T. L., Kroll S. and Shogren J. F. (2005) 'The impact of endowment heterogeneity and origin on public good contributions: evidence from the lab', *Journal of Economic Behavior and Organization,* 57/3: 357–65.

Cox J. C., Dinkin S. and Swarthout J. T. (2001) 'Endogeneous entry and exit in common value auctions', *Experimental Economics,* 4: 163–81.

Español F. (2018) 'Identifying Patterns of Human Behavior: An Analysis on Experimental Data of the Public Goods Game', Thesis, University of Barcelona.

Falk A. and Heckman J. J. (2009) 'Lab experiments are a major source of knowledge in the social sciences', *Science,* 326: 535–8.

Fehr E. and Schmidt K. M. (1999) 'A theory of fairness, competition, and cooperation', *Quarterly Journal of Economics,* 114/3: 817–68.

Fischbacher U. (2007) 'Z-Tree: Zurich toolbox for ready-made economic experiments', *Experimental Economics,* 10/2: 171–8.

Gampfer R. (2014) 'Do individuals care about fairness in burden sharing for climate change mitigation? Evidence from a lab experiment', *Climatic Change,* 124/1-2: 65–77.

Hargreaves Heap S. P., Ramalingam A. and Stoddard B. V. (2016) 'Endowment inequality in public goods games: a re-examination', *Economics Letters,* 146: 4–7.

Kahneman D., Knetsch J. L. and Tahler R. (1986) 'Fairness as a constraint on profit seeking: entitlements in the market', *American Economic Review,* 75/4: 728–41.

Keser C., Markstädter A. and Schmidt M. (2017) 'Mandatory minimum contributions, heterogeneous endowments and voluntary public-good provision', *Games and Economic Behavior,* 101: 291–310.

Kotchen M. J. (2018) 'Which social cost of carbon? A theoretical perspective', *Journal of the Association of Environmental and Resource Economists,* 5/3: 673–94.

Kravis I. B. and Davenport M. W. S. (1963) 'The political arithmetic of international burden-sharing', *Journal of Political Economy,* 71/4: 309–30.

Kroll S. and Shafran A. P. (2018) 'Spatial externalities and risk in interdependent security games', *Journal of Risk and Uncertainty,* 56/3: 237–57.

Lenton T. M., Rockström J., Gaffney O., Rahmstorf S., Richardson K., Steffen W. and Schellnhuber H. J. (2019) 'Climate tipping points—too risky to bet against', *Nature,* 575: 592–5.

Maas A., Goemans C., Manning D., Kroll S. and Brown T. (2017) 'Dilemmas, coordination and defection: how uncertain tipping points induce common pool resource destruction', *Games and Economic Behavior,* 104: 760–74.

Madani K. and Dinar A. (2012) 'Cooperative institutions for sustainable common pool resource management: application to groundwater', *Water Resources Research,* 48/9: W09553.

Mazi K., Koussis A. D. and Destouni G. (2013) 'Tipping points for seawater intrusion in coastal aquifers under rising sea level', *Environmental Research Letters,* 8/1: 014001.

Milinski M., Sommerfeld R. D., Krambeck H.-J., Reed F. A. and Marotzke J. (2008) 'The collective-risk social dilemma and the prevention of simulated dangerous climate change', *Proceedings of the National Academy of Sciences,* 105/7: 2291–4.

Milinski M., Röhl T. and Marotzke J. (2011) 'Cooperative interaction of rich and poor can be catalyzed by intermediate climate targets', *Climatic Change,* 109/3-4: 807–14.

Musgrave R. A. (1959) *The Theory of Public Finance: A Study in Public Economy*. New York: McGraw-Hill.

Ostrom E. (2006) 'The value-added of laboratory experiments for the study of institutions and common-pool resources', *Journal of Economic Behavior & Organization,* 61/2: 149–63.

Page E. A. (2008) 'Distributing the burdens of climate change', *Environmental Politics,* 17/4: 556–75.

Rapoport A. and Suleiman R. (1993) 'Incremental contribution in step-level public goods games with asymmetric players', *Organizational Behavior and Human Decision Processes,* 55/2: 171–94.

Vicens J., Bueno-Guerra N., Gutiérrez-Roig M., Gracia-Lázaro C., Gómez-Gardeñes J., Perelló J., Sánchez A., Moreno Y. and Duch J. (2018) 'Resource heterogeneity leads to unjust effort distribution in climate change mitigation', *PLoS One,* 13/10: e0204369.

Waichman I., Requate T., Karde M. and Milinski M. (2018), 'Challenging conventional wisdom: experimental evidence on heterogeneity and coordination in avoiding a collective catastrophic event', Economics Working Papers 2018-05, Department of Economics, Christian-Albrechts-University of Kiel.

Weinzierl M. (2017) 'Popular acceptance of inequality due to Innate Brute Luck and support for classical benefit-based taxation', *Journal of Public Economics,* 155: 54–63.

Zelmer J. (2003) 'Linear public goods experiments: a meta-analysis', *Experimental Economics,* 6/3: 299–320.