Inequality, communication, and the avoidance of disastrous climate change in a public goods game

Alessandro Tavoni[a,1], Astrid Dannenberg[b], Giorgos Kallis[c], and Andreas Löschel[b,d,e]

[a]Grantham Research Institute and Centre for Climate Change Economics and Policy, London School of Economics, London WC2A 2AZ, United Kingdom; [b]Department of Environmental and Resource Economics, Centre for European Economic Research, 68161 Mannheim, Germany; [c]Institució Catalana de Recerca i Estudis Avançats, and Institut de Ciencia i Tecnologia Ambientals, Universidad Autonoma de Barcelona, 08193 Bellatera, Spain; [d]Alfred Weber Institute for Economics, University of Heidelberg, 69115 Heidelberg, Germany; and [e]Centre for Climate Economics and Policy, Australian National University, Canberra, ACT 0200, Australia

Edited* by Simon A. Levin, Princeton University, Princeton, NJ, and approved May 24, 2011 (received for review February 17, 2011)

International efforts to provide global public goods often face the challenges of coordinating national contributions and distributing costs equitably in the face of uncertainty, inequality, and free-riding incentives. In an experimental setting, we distribute endowments unequally among a group of people who can reach a fixed target sum through successive money contributions, knowing that if they fail, they will lose all their remaining money with 50% probability. In some treatments, we give players the option to communicate intended contributions. We find that inequality reduces the prospects of reaching the target but that communication increases success dramatically. Successful groups tend to eliminate inequality over the course of the game, with rich players signaling willingness to redistribute early on. Our results suggest that coordination-promoting institutions and early redistribution from richer to poorer nations are both decisive for the avoidance of global calamities, such as disruptive climate change.

threshold public good | climate burden | experimental economics | cooperation | self-serving bias

Preserving the global climate commons is one of the biggest collective action problems humanity has ever faced (1); evidence suggests that we have already exceeded the planet's "safe operating space" in the climate system (2). Containing the rise in global mean temperature is a global public good, wherein the benefits of efforts to reduce emissions are shared by all, irrespective of individual contributions. Such disconnect between individual and collective interest is a prime cause of public goods underprovision (3–7). Although public goods experiments under controlled conditions oversimplify the complexity of international climate action (8), they nonetheless shed light on the relative importance of factors that affect its success (9). Standard public good games are concerned with the creation of a collective gain (10–15). Climate change, however, is about avoiding an uncertain public bad. This has been framed as a "collective-risk social dilemma," a threshold public good game of loss avoidance played with sequential contributions to a fund aimed at avoiding a probabilistic loss arising if the target is missed (16, 17). By capturing catastrophic climate change, this game has shed new light on the issue. It lacks, however, important features that may be determinant for the findings: inequality between participants and the opportunity to communicate with one another.

International progress in reducing CO_2 emissions has been remarkably slow, not least because of free-riding incentives, as partly captured by the threshold public goods game of loss avoidance (16). The challenge of this game, however, is coordination. Players are best off when synchronizing contributions in the face of multiple equilibria (3, 18). The game therefore calls for communication. The latest climate agreements negotiated in Copenhagen and Cancun introduced a pledge and review system of voluntary emission reduction commitments for 2020 (19). Can such a simple mechanism of communicating intentions be effective to enhance coordination?

Optimism from reaching a global agreement following Cancun is shadowed by concerns over implementation and particularly whether richer nations will go far enough in financing abatement and adaptation for poorer nations (20). Equity concerns over the distribution of emission cuts and associated costs are at the heart of the sustainability of international climate change action (21, 22). Inequality has been studied extensively in the context of collective action problems. The presence of inequality is often found to complicate cooperation (23–25), although communication between users tends to improve the likelihood of cooperation (26, 27). Different patterns of interaction are observed depending on the type and cause of inequality and on the type of resource at stake (28). Given these findings, we examine how inequality and potential differences in equity concerns between rich and poor affect their ability to coordinate efforts, and how this is mediated through communication of contribution intentions.

An essential feature of the global climate change game is that inequality in endowments is mirrored by inequality in past appropriation of the climate commons; roughly speaking, the richer a nation is, the more "carbon space" it has used in the atmosphere attributable to past greenhouse gas emissions (29, 30). We test its implications in the laboratory, with 240 students randomly assigned to groups of 6. Specifically, we assess the effects of inherited inequality in wealth and appropriation on coordination success in reaching a safety target, and how this is mediated through communication of contribution intentions. As in the study by Milinski et al. (16), each player was endowed with €40 that could be invested in climate protection. Players could choose between an investment of €0, €2, or €4 per round. The target was to invest €120 collectively by the 10th and final round so as to avoid simulated dangerous climate change and to secure what was left in the private account. Groups that failed to invest at least €120 lost all their savings with a 50% probability. Players did not know the identity of their team's members; after each round, they were informed about the others' contributions, the aggregate group contribution in that round, and the cumulative past contribution of each player and of the group as a whole (*Materials and Methods*).

To capture the idea of inheritance of past wealth and debt, we started the game with three inactive rounds in which players had no freedom to choose because contributions were determined by the computer. In the control treatment ("*Base*"), the computer allocated symmetrically to all players €2 per round. In the "*Base-Unequal*" treatment, the computer allocated asymmetrically to half of the group €4 per round and to the other half €0 per round. "Rich" players hence entered round 4 with €40, and "poor"

Author contributions: A.T., A.D., G.K., and A.L. designed research; A.T. and A.D. performed research; A.T. and A.D. analyzed data; and A.T., A.D., G.K., and A.L. wrote the paper.

The authors declare no conflict of interest.

*This Direct Submission article had a prearranged editor.

[1]To whom correspondence should be addressed. E-mail: a.tavoni@lse.ac.uk.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1102493108/-/DCSupplemental.

Table 1. End payoffs (and corresponding climate account values for the group in parenthesis) arising if the three pure strategies were adopted by all players for the seven active rounds

Treatment	€0 per round	€2 per round	€4 per round
Symmetrical	(36)	(120)	(204)
w_{all} = €34	17*	20	6
Asymmetrical	(36)	(120)	(204)
w_{rich} = €40	20*	26	12
w_{poor} = €28	14*	14	0

In the symmetrical treatments (*Base* and *Pledge*), all group members begin active play having contributed €6 in the previous three rounds, leaving them with a disposable endowment, w_{all} = €34; in the asymmetrical treatments (*Base-Unequal* and *Pledge-Unequal*), three rich players have no prior contributions and the three poor players have prior contributions of €12, leaving them with w_{rich} = €40 and w_{poor} = €28, respectively.
*Expected values based on the 50% probability of account loss when the target sum of €120 is not reached.

players entered round 4 with €28. Irrespective of the treatment, for the sake of comparability, all groups started the active phase with €36 in the climate account. In two treatments, players were given the option to announce what they planned to invest during the game: one time at the end of the three inactive rounds and again at the end of round 7. Subjects knew that pledges were nonbinding. The *"Pledge"* treatment introduced the pledges to the symmetrical case, whereas the "*Pledge-Unequal*" treatment implemented the pledges in the asymmetrical case.

The multiplicity of equilibria in the game makes classification virtually impossible. The game is a modified *n*-person stochastic threshold public goods game, with a total of 10 rounds, of which only 7 allow freedom of choice over the three possible actions. Both contributing nothing and contributing €2 in each round are (symmetrical) pure strategy Nash equilibria, because unilateral deviations are nonprofitable (31) (Table 1). Depending on the round and the path that led to it, a contribution of €4, bringing the individual investment above €20, may still be optimal if successful in guaranteeing that past investments are not wasted. Conversely, if at a certain stage, the target becomes out of reach because of insufficient members' contributions, one's best response is to stop contributing and play the odds.

In the symmetrical treatments, each group trajectory leading to a cumulative contribution of €120, irrespective of individual contributions provided that each subject invests at most €22 overall, is a Nash equilibrium. This is the case because the latter investment translates into a payoff of €18, which is above the €17 that is expected when all players choose not to contribute to the public good (Table 1, second column). Therefore, individuals can maximize the payoff of the game by choosing the intermediate level of contribution, invest a further €14 over rounds 4–10, and secure the €20.

In the asymmetrical treatments, as a result of the different disposable endowments of rich and poor players, the former gain the most when the climate is protected with equal burden sharing in the active rounds (€26, resulting from an investment of €14). Relative to the no-contribution equilibrium, it is more appealing because the rich will be at least as well off when investing €20 at most. The poor, on the other hand, do not stand to gain from the equal burden-sharing equilibrium in the active rounds, assuming risk neutrality. Given the early round contributions of €12, only

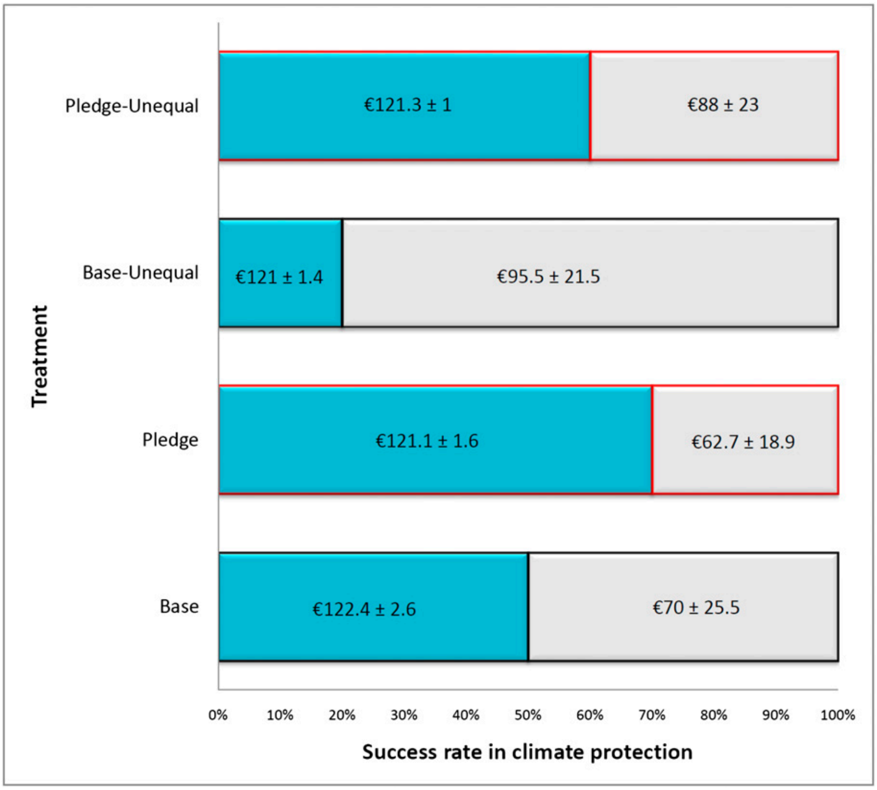

Fig. 1. Success rate in avoiding dangerous climate change. The lower two treatments are symmetrical, and the upper two are asymmetrical. The blue sections of the bars indicate the % of successful groups, whereas the gray sections indicate the corresponding failures (with red contours for the treatments with communication). (*Insets*) For both group classes, the average investments (inclusive of the €36 collected in the first three rounds) and SDs are shown. Only in *Pledge* was the outcome somewhat close to the rational prediction of all groups reaching the target (n = 10; P = 0.082, binomial test). Further analyses are available in *SI Text*.

by investing less than €14 in the active rounds (with the group still reaching the threshold) can these players have a higher expectation than by not investing in the public good.

The game design allows for such redistribution. The rich have a surplus of €12 in the €2 per active round equilibrium relative to the poor and can, in principle, forego part or all of it by investing more and allowing the poor to decrease their investment correspondingly. An average of €3 per round for the rich and €1 per round for the poor almost equalizes contributions (and expected payoffs) among the players. With full redistribution, rich and poor have a final payoff of €20, which, for the rich, is still rational in the sense of not being welfare diminishing relative to not contributing anything.

Lastly, note that a threshold public goods game like this one [and that by Milinski et al. (16)] differs from the majority of games used to investigate the climate change cooperation problem (32). In particular, the problem of enforcement is facilitated by the "disastrous" consequences of contributing less than €120, which therefore becomes a focal contribution level. The traditional formulation, in contrast, does not include catastrophic climate change but only gradual effects (mostly assuming linear benefits and nonlinear costs). The introduction of the catastrophe makes these curves discontinuous.

Results

Results show that inequality makes success harder but that the *Pledge* treatment option increases success dramatically (Fig. 1). Both *Pledge* treatments were well above the corresponding ones without pledges. Income inequality reduced the prospects of success: 5 of 10 groups succeeded in the *Base* treatment vs. 2 of 10 in the *Base-Unequal* treatment. In the latter, investment by the failing groups was €15 higher [n = 13; P = 0.039, two-sided Mann–Whitney–Wilcoxon (MWW) test], indicating that inequality also led to poorer coordination on the nonprovision outcome. The *Pledge* treatment option had more effect under conditions of inequality: Success rates tripled from 2 of 10 in the *Base-Unequal* treatment to 6 of 10 in the *Pledge-Unequal* treatment (n = 20; P = 0.085, one-sided Fisher's exact test). The latter success rate (6 of 10) is not significantly different from the 7 of 10 achieved by participants of the symmetrical *Pledge* treatment (P = 0.500), indicating that inequality is a less serious threat once a better coordination mechanism is introduced. This positive effect of communication is remarkable, given the fact that the incentives to coordinate toward a high contribution level are relatively weak. Going for the €2 per round strategy provides only moderate benefits compared with zero contribution, and, unlike the latter, it requires the cooperation of the remaining group members.

Although nonbinding, players respected pledges. Following the second pledge, average cumulative contributions in rounds 8–10 were €31.8 and €30 in *Pledge-Unequal* and *Pledge*, respectively, and the stated amounts were €32.6 and €29.6. The closer the pledges were to actual contributions, the higher was the probability of group success. As the difference between cumulative contributions and pledged amounts increases, the probability of a player being in a successful group decreases significantly (Fig. 2).

Successful groups were strikingly effective in eliminating the inherited inequality. In the two unequal treatments, the difference in contributions between rich and poor players belonging to successful groups is not significant (Fig. 3*A*; n = 16; P = 0.820, two-sided MWW test). Even in the absence of communication, participants of successful groups tacitly coordinated on an equalizing redistribution that offset the original endowment asymmetry. Conversely, the difference in contributions between rich and poor is significant in failing groups (€12.83 by the rich and €18.17 by the poor, n = 24; P = 0.014), indicating that such redistribution did not take place (Fig. 3*B*).

ENVIRONMENTAL SCIENCES

SUSTAINABILITY SCIENCE

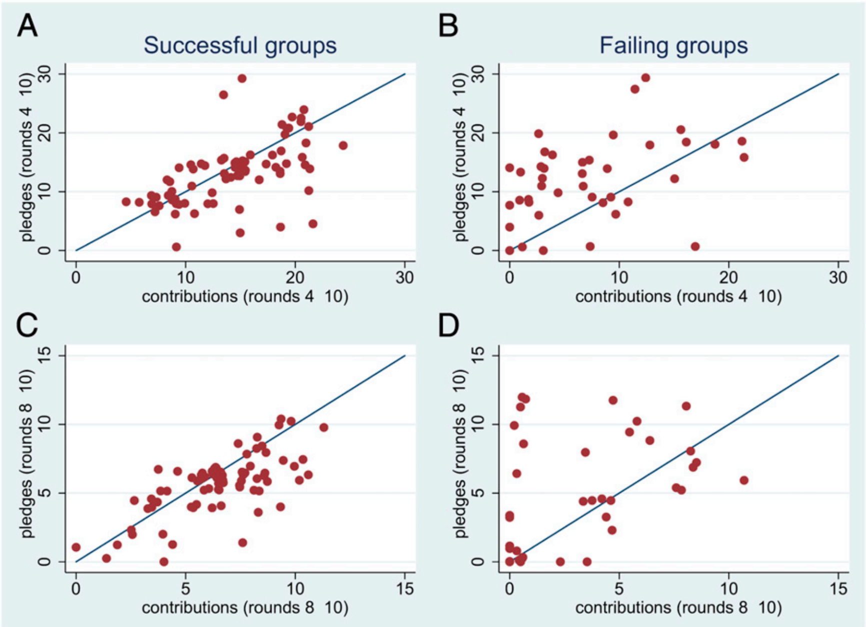

Fig. 2. Departure from announced contributions and its link to success. The probability that a player belongs to a successful group decreases with the contribution-pledge gap, i.e., with the differences between cumulative contributions and the corresponding amounts pledged both early (rounds 4–10, Probit; P = 0.002) and later (rounds 8–10, Probit; P = 0.032) in the game. All regressions have group-cluster robust SEs to take into account outcome interdependence among participants; regression tables and marginal effects interpretation are provided in *SI Text*. (*A* and *B*) Link between success and adherence to the initial pledge is visually confirmed. For the groups that provided the public good (*A*), the contribution-pledge gap is tighter than for the unsuccessful ones (*B*), as indicated by the dispersion around the bisector. Similarly for the second pledge, greater clustering around the bisector takes place in *C* than in *D*. A small random noise (5%) has been inserted to make all data points visible.

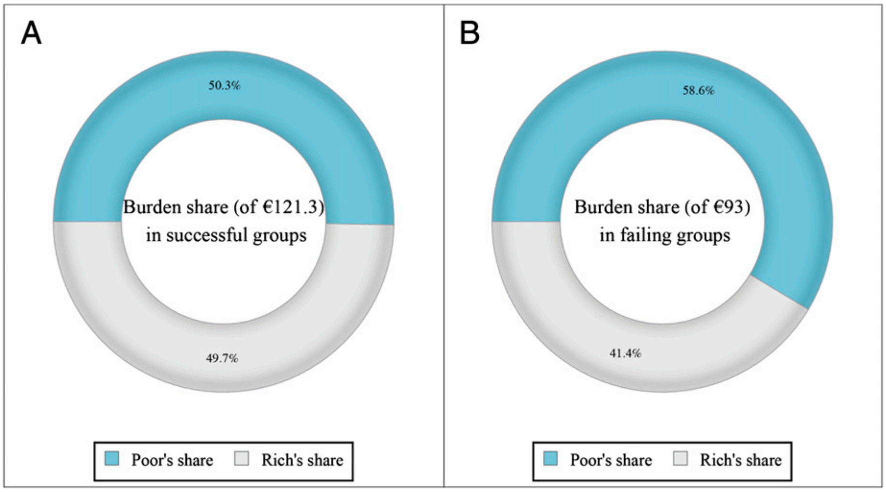

Fig. 3. Relative share of the total contributions taken up by players with different endowments, depending on which group they belong to. (*A*) In successful groups partaking of the treatments with unequal endowments (*Base-Unequal* and *Pledge-Unequal*), the rich compensated the poor by investing more in the active rounds and equalized cumulative contributions over the entire game at approximately €20. (*B*) In failing groups, such wealth redistribution did not take place to the same extent. The initial gap of €12 between the rich and poor was not fully offset because the former invested, on average, €12.83 each over the entire game (collectively contributing ∼40% of the €93 provided), whereas the poor invested €18.17 (collectively contributing ∼60% of €93).

Signaling willingness to invest in the public good rather than to gamble early on was critical for the fate of the game. Successful group members provided, on average, €1.92 in round 4, whereas failing group members provided €1.25 ($n = 40$; $P = 0.000$, two-sided MWW test). Early signals by the rich of willingness to redistribute were decisive in the asymmetrical games. On average, rich players in successful groups contributed €3.17 in round 4, whereas they contributed €2.06 in failing groups ($n = 20$; $P = 0.005$, two-sided MWW test). Cumulative contributions by the rich over rounds 4–6 were €9.83 in successful groups, whereas the rich in failing groups appeared to be unwilling to commit to early redistribution and invested only €6.67 ($n = 20$; $P = 0.004$).

The questionnaire that followed the game (*SI Text*) confirms that the rich's fairness perceptions and willingness to redistribute were decisive for success. Being confronted with the statement that "the rich players should contribute more during the active rounds than the poor players," 75% of the rich in successful groups but only 53% of the rich in failing groups agreed with that claim ($n = 60$; $P = 0.071$, one-sided Fisher's exact test). Therefore, the rich's opinion in that question and the group's success are significantly correlated ($n = 60$; $P = 0.086$, Spearman's correlation test). Furthermore, subjects' responses show a clear self-serving bias of fairness perceptions. The acceptance of the above claim is highly dependent on the player's wealth ($n = 120$; $P = 0.000$, Spearman's correlation test). In numbers, 90% of the poor but only 62% of the rich support the claim for redistribution ($n = 120$; $P = 0.000$, one-sided Fisher's exact test). This bias, which has been found also in climate negotiations (22), appears to be an important determinant for effective coordination.

Discussion

We find unambiguous evidence that the poor are not willing to compensate for the rich's inaction. These findings suggest that early leadership by the richer nations, in addition to appropriate coordination mechanisms, is instrumental to the avoidance of disastrous climate change. Extrapolation from our results, however, should be cautious (33). Controlling CO_2 emissions is a much more complex task than the one of coordination on a known threshold faced by the subjects of this experiment (3, 18). Climate change involves considerable uncertainty, especially the prospect of ensuing catastrophes. Many effects of global warming will be felt gradually; they may provide valuable early warning signals but, at the same time, worsen the free-rider problem. Climate change also entails not only asymmetry in wealth and carbon debt but asymmetry in adaptation capacity and risk exposure (34). Losses, even under catastrophic climate change, will be unequally distributed depending on countries' income or location (35). Different types of inequality stand to have different effects, the more so when in concert (36). The shape of the wealth distribution may also affect outcomes. Whereas an increase in inequality may well enhance the incentives for the rich to contribute more, such an increase may simultaneously reduce the incentives for the poor (29). Future research is needed to bring more realism and complexity in the collective-risk social dilemma, introducing uncertain thresholds and gradual climate change for instance. Experimental games may further help to explore the barriers to cooperation and to identify promising institutions.

Nevertheless, the finding that inequality hampers coordination and makes a coordination-promoting institution indispensable is important. Countries can be expected to coordinate their national efforts to reach a common goal, and communication and agreement on a common fairness notion are preconditions. Success in providing the global climate protection good is inextricably related to the willingness of the rich to take up a sizeable share of the burden early on. Signaling commitment to contribute early on appears decisive for coordination. Unfortunately, communication and consent are not sufficient to tackle climate change. Societies will have to do much more to solve this global collective action problem.

Materials and Methods

The experimental sessions were held in a computer laboratory at the University of Magdeburg, Magdeburg, Germany, using undergraduate and graduate students recruited from the general student population. In total, 240 students participated in the experiment, 60 of whom took part in each treatment. Subjects were seated randomly at linked computers with which they communicated their investment decisions during the game (further details and software demonstration are provided in *SI Text*). At the beginning of a session, a set of written instructions was handed out. The instructions included several numerical examples and control questions that tested subjects' understanding of the game. After reading the instructions and answering the control questions correctly, subjects were randomly assigned to a six-person group and began the game. The subjects did not know their fellows' identities, but they knew that they remained within the same group of players throughout the game. All decisions were made under completely anonymous conditions. The game comprised 10 rounds, with the first 3 rounds involving contributions predetermined by the software. After the 3 fixed rounds, 7 active rounds followed, where subjects could invest €0, €2, or €4 per round. After each round, subjects were informed about individual contributions (via nicknames) and the group contribution as well as cumulative individual contributions and cumulative group contribution up to the current round. Subjects knew that they would either lose their savings (what was left over after they invested a certain amount in climate protection) with 50% probability if the total sum of investment over all rounds fell short of the €120 target or would get their savings for sure if the total sum equaled or exceeded the target. The experimental sessions lasted about 60 min, and subjects earned, on average, €17.23 in the games. Earnings were anonymously paid in cash at the end of the session.

ACKNOWLEDGMENTS. We thank the MaXLab team of the University of Magdeburg, Magdeburg, Germany, for their support in conducting the experiment, as well as M. Milinski for providing the instructions and other information concerning a previously published experiment. This work was supported by the Gottfried Wilhelm Leibniz Scientific Community. A.T. is supported by the Centre for Climate Change Economics and Policy, which is funded by the UK Economic and Social Research Council and Munich Re.

1. Dietz T, Ostrom E, Stern PC (2003) The struggle to govern the commons. *Science* 302:1907–1912.
2. Rockström J, et al. (2009) A safe operating space for humanity. *Nature* 461:472–475.
3. Barrett S (2007) *Why Cooperate? The Incentives to Supply Global Public Goods* (Oxford Univ Press, Oxford).
4. Carraro C, Siniscalco D, eds (1997) *New Directions in the Economic Theory of the Environment* (Cambridge Univ Press, New York).
5. Hardin G (1968) The tragedy of the commons. *Science* 162:1243–1248.
6. Levin SA (1999) *Fragile Dominion: Complexity and the Commons* (Perseus Books, Reading, MA).
7. Ostrom E, Burger J, Field CB, Norgaard RB, Policansky D (1999) Revisiting the commons: Local lessons, global challenges. *Science* 284:278–282.
8. Brekke KA, Johansson-Stenman O (2008) The behavioral economics of climate change. *Oxf Rev Econ Policy* 24:280–297.
9. Inman M (2009) The climate change game. *Nature Rep Clim Change* 3:130–133.
10. Ledyard J (1995) *Handbook of Experimental Economics*, eds Kagel JH, Roth AE (Princeton Univ Press, Princeton), pp 111–194.
11. Sturm B, Weimann J (2006) Experiments in environmental economics and some close relatives. *J Econ Surv* 20:419–457.
12. Ostrom E (2000) *Polycentric Games and Institutions: Readings from the Workshop in Political Theory and Policy Analysis*, ed McGinnis MD (Univ of Michigan Press, Ann Arbor, MI), pp 472–522.
13. Fehr E, Gächter S (2000) Cooperation and punishment in public goods experiments. *Am Econ Rev* 90:980–994.
14. Gürerk Ö, Irlenbusch B, Rockenbach B (2006) The competitive advantage of sanctioning institutions. *Science* 312:108–111.
15. Fischbacher U, Gächter S (2010) Social preferences, beliefs, and the dynamics of free riding in public goods experiments. *Am Econ Rev* 100:541–556.
16. Milinski M, Sommerfeld RD, Krambeck H-J, Reed FA, Marotzke J (2008) The collective-risk social dilemma and the prevention of simulated dangerous climate change. *Proc Natl Acad Sci USA* 105:2291–2294.
17. Dreber A, Nowak MA (2008) Gambling for global goods. *Proc Natl Acad Sci USA* 105:2261–2262.
18. Barrett S (2003) *Environment and Statecraft: The Strategy of Environmental Treaty-Making* (Oxford Univ Press, Oxford).
19. Tollefson J (2010) Last-minute deal saves climate talks. *Nature* 468:875–876.
20. Kintisch E, Regalado A (2010) Climate negotiations. Cancún delegates see the trees through a forest of hot air. *Science* 330:1597.
21. Baer P, et al. (2000) Equity and greenhouse gas responsibility. *Science* 289:2287.
22. Lange A, Löschel A, Vogt C, Ziegler A (2010) On the self-interested use of equity in international climate negotiations. *Eur Econ Rev* 54:359–375.
23. Alesina A, La Ferrara E (2000) Participation in heterogeneous communities. *Q J Econ* 115:847–904.
24. Costa DL, Kahn ME (2003) Civic engagement and community heterogeneity: An economist's perspective. *Perspect Polit* 1:103–112.
25. Anderson LR, Mellor JM, Milyo J (2008) Inequality and public good provision: An experimental analysis. *J Socio-Econ* 37:1010–1028.
26. Ostrom E, Gardner R, Walker J (1994) *Rules, Games, and Common-Pool Resources* (Univ of Michigan Press, Ann Arbor, MI).
27. Hackett S, Schlager E, Walker J (1994) The role of communication in resolving commons dilemmas: Experimental evidence with heterogeneous appropriators. *J Environ Econ Manage* 27:99–126.
28. Baland J-M, Platteau J-P (2007) *Inequality, Cooperation and Environmental Sustainability*, eds Baland J-M, Bardhan P, Bowles S (Princeton Univ Press, Princeton), pp 10–35.
29. Roberts JT, Parks BC (2006) *A Climate of Injustice: Global Inequality, North-South Politics and Climate Policy* (MIT Press, Cambridge, MA).
30. Srinivasan UT, et al. (2008) The debt of nations and the distribution of ecological impacts from human activities. *Proc Natl Acad Sci USA* 105:1768–1773.
31. Nash JF (1950) Equilibrium points in N-person games. *Proc Natl Acad Sci USA* 36:48–49.
32. Finus M (2001) *Game Theory and International Environmental Cooperation* (Edward Elgar, Cheltenham, UK).
33. Levitt SD, List JA (2007) What do laboratory experiments measuring social preferences reveal about the real world? *J Econ Perspect* 21:153–174.
34. Kasperson RE, et al. (2005) *Ecosystems and Human Well-Being. Current State and Trends*, eds Hassan RM, Scholes R, Ash N (Island Press, Washington, DC), Vol 1, pp 143–164.
35. Adger WN, et al. (2007) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, eds Parry M, Canziani OF, Palutikof J, van der Linden P, Hanson CE (Cambridge Univ Press, Cambridge, UK), pp 717–744.
36. Baland J-M, Platteau JP (1997) Wealth inequality and efficiency in the commons. *Oxf Econ Pap* 49:451–482.

Supporting Information

Tavoni et al. 10.1073/pnas.1102493108

SI Materials and Methods

Methodological Details. Most experiments on public goods use linear public goods games, where participants have the option to invest a fraction of their endowments in a public good by means of a voluntary contributions mechanism (1). Typically, the returns to the investment are equally shared among the participants according to the marginal per capita return. We depart from this standard formulation in many ways. First, the provision of the public good is sequential, because multiple stages of contributions (10 rounds) are performed before the assessment of the group effectiveness in preventing simulated catastrophic climate change. Second, the objective of the game is to avoid a loss rather than creating a surplus by contributing to a public good (with higher group contributions leading to higher returns to the players). Here, players' contributions to the public good make them collectively better off only insofar as they are sufficient to reach a threshold by the final round (€120). All contributions below (or above) that threshold are wasted because they fail to secure the keeping of the private accounts by the participants (or have no additional benefit if above the threshold). This feature leads to the next salient one, concerning the probabilistic nature of the losses. To account for the uncertainty involved in climatic change, the actions of the six players forming a group taking part in the game have consequences that are not deterministic. If the players collectively fail to reach the target required to avoid climate catastrophe, they will lose their savings in the private account (what is left of the initial €40 endowment after the contributions to the public good) with a probability of 50%. Because both the climate threshold and the probability of the climate catastrophe are known, the players' primary challenge here is to coordinate rather than to just increase their contributions.*

The probability of the climate catastrophe was chosen in light of the results of the experiment by Milinski et al. (2), who developed and tested the above departures, which we aim to enrich with features that will be discussed below. It is therefore worth taking a closer look at their experiment. In a nutshell, they implemented the above setup, with individuals deciding in each of the 10 rounds of the game whether to contribute €0, €2, or €4 to the climate account, with each group being presented with one of three different treatments corresponding to three probabilities of savings loss: 90%, 50%, and 10%. These yielded the following levels of success in avoiding simulated climate change: 50%, 10%, and 0%. With the highest stakes, because of the larger gains in expected value from reaching the target, coordination was most effective. Half of the participating groups were successful in collecting at least €120, whereas only 1 of 10 groups succeeded in the 50% treatment and no group succeeded in the treatment with a 10% probability of incurring the loss. Note that the last result is not surprising from a rationality standpoint, because a player contributing €0 in all rounds would have expected earnings of €36 compared with earnings of €20 and €0 by following the remaining two pure strategies of contributions of €2 per round and €4 per round. Only in the 90% treatment does the social optimum coincide with the strategy of €2 per round because it would lead to certain earnings of €20 if adopted by all subjects, compared with expected earnings of €4 if all adopt the €0 per round strategy and a certain outcome of €0 if they follow the €4 per round strategy.

Our baseline experimental design closely follows (2), with six individuals playing together in a group, each endowed with €40. The players decided in each of the active rounds of the game whether to contribute €0 ("no contribution"), €2 ("intermediate contribution"), or €4 ("high contribution") to the climate account. All groups were presented with the probability of a savings loss of 50%. This was chosen because, as illustrated in Table 1, it favors the symmetrical equilibrium, where all contribute €2 per round (at least in symmetrical treatments and in asymmetrical treatments for rich players) over the no-contribution equilibrium, although retaining a high temptation to defect and take a gamble. Further, we avoided extreme probabilities [e.g., 10%, 90% (3)] to avoid confusion with certain outcomes and, in particular, for the following reasons: 10% disaster probability makes the game trivial from a game theoretical perspective, because players are better off by not providing the public good, and 90% probability, on the other hand, makes the noncooperative equilibrium unattractive because of almost certain loss in case of failure to reach the target. After each round, the players were informed about all individual contributions and the aggregate group contribution in that round as well as the cumulative past contribution of each player and the group. As in the study by Milinski et al. (2), players were assigned nicknames to keep their identity private. Because the focus of this paper is to test in the laboratory for the role of inherited inequalities in informing the debate on climate change, we introduced a series of treatments aimed at capturing features of asymmetry among participants in terms of wealth, past contributions, and future commitment announcements.

To induce subjects to perceive the inequalities among them as the result of past actions, we modified the game described above by replacing the first three rounds with three inactive ones in which half of the group had only the option of choosing a €0 per round contribution, whereas the remaining three players were bound to a €4 per round contribution (Fig. S1).

Rather than externally imposing different endowments from the beginning of the experiment, players were all told they had the full €40 endowment before the start but witnessed through the first three rounds a growing divergence between high and low contributors. As a result of these three inactive rounds, the players began the active play consisting of seven rounds with substantial "inherited" differences. Those who forcefully contributed €12 before round 4 had €28 left in their private accounts, whereas those who previously did not contribute anything to the public good found themselves with the entire endowment available for the ensuing seven rounds. We call this treatment "*Base-Unequal*." The current generation inherited wealth (and "debts") from the first generation without having a say on it but simply as the result of past actions. This situation is reminiscent of global CO_2 emissions, with developed countries owing much of their prosperity to past carbon-intensive industrialization relative to developing countries with historically and proportionately smaller carbon footprints and wealth.

To single out the effect on coordination of the introduced asymmetry, a "*Base*" treatment was performed without such unequalizing redistribution. In it, subjects went through three inactive rounds in which they all had no other option than to choose the intermediate contribution of €2 per round. These three inactive rounds might render the intermediate strategy more focal (a more in-depth discussion is provided in the Impact of the Computerized Rounds section in *SI Text*).

*Scott Barrett theoretically examines what happens if these (and other) conditions do not apply in the working paper "Climate Treaties and Approaching Catastrophes". Available at http://cbey.research.yale.edu/uploads/Environmental%20Economics%20Seminar/Yale%20seminar%20paper.pdf. Accessed December 19, 2010.

Finally, because communication is not simply "cheap talk" in coordination games but may have an important effect on the ability to coordinate, we implemented two treatments in which the subjects had the opportunity to make future commitment announcements. The "*Pledge*" treatment introduced two pledge stages to the symmetrical case, whereas the "*Pledge-Unequal*" treatment implemented two pledge stages in the asymmetrical case. In both pledge treatments, it was common knowledge that the pledges were nonbinding. The first pledge stage occurred after the (fixed) first three rounds. The subjects simultaneously and independently announced their intended contributions for the subsequent seven rounds. Afterward, the players saw the "intended climate account," which contained the individual contributions from the first three (inactive) rounds plus the individual pledges. Thereby, they immediately detected whether the intended contributions would be sufficient to avoid catastrophic climate change. The second pledge stage took place after round 7. Similar to the first pledge, the players simultaneously and independently announced their intended contributions for the last three rounds and were subsequently informed about the "new intended climate account" that included past contributions and the pledges. Table S1 summarizes the key features of our experimental design and the number of participants in each session.

The experiment was run in May 2010 in the MaxLab laboratory at the University of Magdeburg, Magdeburg, Germany. In total, 240 students participated in the experiment, whereby the pool consisted of a mixture of students with an economic or business major (60%) and students with a noneconomic major (40%). Most of the students were experienced because they had participated in three or more experiments before (88%), whereas only a few students were inexperienced (12%). Sixty subjects took part in each treatment. No subject participated in more than one treatment. Sessions lasted about 60 min. For each session, we recruited either 12 or 18 subjects. Each subject was seated at a linked computer terminal that was used to transmit all decision and payoff information. We used Z-tree software (3) for programming. Once the individuals were seated and logged onto the terminals, a set of written instructions was handed out. Experimental instructions (Experimental Instructions for the Treatments *Pledge* and *Pledge-Unequal* section in *SI Text*) included a numerical example and control questions to ensure that all subjects understood the games. At the beginning of the experiment, subjects were randomly assigned to groups of 6. The subjects were not aware of whom they were grouped with, but they did know that they remained within the same group of players throughout the 10 rounds. After the final round, the players were informed whether the group had successfully reached the threshold of €120. Afterward, they were asked to fill out a short questionnaire. The questionnaire was designed to elicit the players' impressions and motivation during the game (Questionnaire section in *SI Text*). At the end of the experiment, one of two table tennis balls was publicly drawn from a bag by a volunteer student. If there was the number 1 on the ball, all players in the groups that had not reached the threshold kept the money (that was left in their private account). If there was the number 2 on the ball, these players lost their money. Of the 20 groups that did not reach the threshold, 11 groups had good luck and kept their money and 9 groups had bad luck and lost their money. No show-up fee was administered. On average, a subject earned €17.23 in the games; the maximum payoff was €40, and the minimum payoff was €0.

The money allocated to the climate account was used to buy and withdraw CO_2 emission certificates traded in the European Union emission trading scheme (EU ETS).[†] If a group had successfully reached the threshold, all the climate account money was used in this way. In case of a failing group, only half of the climate account money was used for emission certificates. Thereby, we introduced a specific field context to the experiment that made the task more realistic and might have increased participants' motivation (although equally in all treatments). The experimental instructions contained a short explanation of the EU ETS and the above-mentioned rules (Experimental Instructions for the Treatments *Pledge* and *Pledge-Unequal* section in *SI Text*). We announced furthermore that the purchase and suspension of certificates would be certified by a notary and that the overall amount of certificates and notarial acknowledgment could be found at a permanent website.[‡] Overall, we spent €3,248 for emission certificates, which corresponds to 212 tons of CO_2, given a price of €15.3 per ton.[§]

Experimental Instructions for the Treatments *Pledge* and *Pledge-Unequal* (translated from German). Welcome to the experiment!

General notice. In this experiment, you can earn money. To make this experiment a success, please do not talk to the other participants at all or draw any other attention to yourself. Please read the following rules of the experiment attentively. Should you have any questions, please signal us. At the end of the instructions, you will find several control questions. Please answer all questions, and signal us when you have finished. We will then come to you and check your answers.

Climate change. Now, we will introduce you to a game simulating climate change. Global climate change is seen as a serious environmental problem faced by mankind. The great majority of climate scientists expect the global average temperature to rise by 1.1–6.4 °C until the year 2100. There is hardly any denial that mankind largely contributes to climate change by emitting greenhouse gases, especially CO_2. CO_2 originates from burning of fossil fuels like coal, oil, or natural gas in industrial processes and energy production and from combustion engines of cars and lorries. CO_2 is a global pollutant (i.e., each quantity unit of CO_2 emitted has the same effect on the climate regardless of the location where the emission has occurred).

Rules of play. In total, six players are involved in the game; thus, in addition to you, there are five other players. Every player faces the same decision-making problem. At the beginning of the experiment, you will receive starting capital (€40) credited to your private account. During the experiment, you can use money from your account or not. In the end, your account balance will be paid out to you in cash. You will be making your decisions anonymously. To guarantee this, you will be assigned a nickname for the playing time. The nicknames are the moons of our solar system (Ananke, Telesto, Despina, Japetus, Kallisto, and Metis). You will find your name on the lower left side of your screen. During the course of the experiment, you will be playing exactly 10 climate rounds. In these rounds, you can invest into the attempt to protect the climate and to evade dangerous climate change. Among other things, dangerous climate change will result in significant economic losses, which will be simulated in this experiment. In each climate round of the game, all six players will be asked simultaneously, "How much do you want to invest into climate protection?"

Possible answers are €0, €2, or €4. Only when each player has made his choice will all decisions be displayed simultaneously. After that, the computer will credit all invested amounts to an account for climate protection ("climate account"). At the end of the game (after exactly 10 rounds), the computer will compare the climate account balance with a predetermined amount (€120). This amount must be earned to evade dangerous climate

[†]For information about the EU ETS, the European Commission official website can be found at http://ec.europa.eu/environment/climat/emission/index_en.htm.

[‡]http://www.zew.de/en/topthemen/meldung_show.php?%20LFDNR=1517&KATEGORIE=2.

[§]For emission certificate prices, visit http://www.eex.com/en. We thank UniCredit Bank AG, Germany, for assistance in the certificate purchase.

change. It will be earned if every player pays, on average, €2 per round into climate protection. If this is the case, €12 will be paid into the climate account per round. If the necessary amount of €120 has been earned, all players will be paid out the amount remaining in their private accounts. The remaining amount consists of the starting capital of €40 minus the sum paid into the climate account. If the necessary amount of €120 has not been earned, dangerous climate change will occur with a probability of 50% (in 5 of 10 cases) and this will result in significant economic losses. If this probability arises, you will lose all the money left in your account and no one will be paid out anything. With another probability of 50% (in 5 of 10 cases), you will keep your money and be paid out the amount in your private account after the game. We will draw the probability by lot in your presence. The payout will be made anonymously. Your fellow players will not learn your identity. Please note the following two particularities in the game. First, the decisions of the six players in the first three rounds are predetermined by the computer. This means that you, and your fellow players, cannot decide freely how much you want to invest in climate protection in the first three rounds. Instead, you will be offered an option that you have to choose.

Please note that the predetermined investments of the first three rounds will already change the amounts in the climate account and the players' accounts. Starting in round 4, you will decide freely which amounts you want to invest into climate protection. Second, all players can issue declarations of intent about how much they want to invest in climate protection in the following rounds. The declarations are not binding for the investment decisions in the following rounds. The first declaration of intent is issued after round 3. All players will simultaneously state how much they plan to invest into climate protection in the next seven rounds in total. When all players have stated their declarations of intent, the "planned climate account" will be displayed. The planned climate account shows the investments of each player for the first three rounds plus the investments planned for the remaining seven rounds. After round 7, all players will be given the opportunity to revise their declarations of intent. All players will then simultaneously state their planned total investments into climate protection for the next three rounds. When all players have stated their declarations of intent, the "newly planned climate account" will be displayed. The newly planned climate account shows how much each player has already invested in the first seven rounds plus the planned investments for the remaining three rounds.

Example. In this example, you see the decisions made by the six players in one round (Fig. S2).

The column on the right side ("Investitionen Runde 6") shows the investments made in the current round. Players Ananke, Telesto, and Despina have not paid anything into the climate account, whereas players Japetus, Kallisto, and Metis each have paid €4. A total of €12 has been paid and, by that, been credited to the climate account. The column in the middle ("Investitionen Runden 1–6 insgesamt") shows the total investments made by each player in rounds 1–6. Players Ananke, Telesto, and Kallisto each have paid €12 into the climate account in the first six rounds. Despina has paid €14, Japetus has paid €10, and Metis has paid €8 in the first six rounds. By that, a total of €68 has been paid into the climate account.

The column on the left ("geplantes Klimakonto Runden 1–10") shows the planned climate account after the first declaration of intent. The value stated per player shows the investments made in the first three rounds plus the planned investments for the remaining seven rounds. This exact information will be displayed after each climate round.

Use of the money in the climate account. If the necessary amount of €120 has been earned to evade climate change, we will buy CO_2 emission certificates for the total amount in the climate account and retire them. If the necessary amount of €120 has not been earned, we will use half of the amount in the climate account to buy CO_2 emission certificates and retire them (we will keep the rest of the money). By purchasing and retiring the CO_2 emission certificates, we contribute to the abatement of climate change. We will now explain to you how this works. In 2005, the EU implemented the ETS for CO_2. Emissions trading is the central instrument of climate policy in Europe. It follows a simple principle: The European Commission, together with the member states, has determined the amount of CO_2 to be emitted altogether in the respective sectors (energy production and energy-intensive industries) until 2020. This total amount will be distributed to the companies by the state in the form of emission rights ("certificates"). For each quantity unit of CO_2 emitted, the company has to give a certificate to the state. The certificates can be traded between companies.

For each quantity unit of CO_2 emitted (e.g., by a power plant), the plant operator has to prove his permission to do so in the form of a certificate. This leads to an important consequence: If the total amount of certificates is reduced, the total emissions will be lower, simply because plant operators do not possess enough emission allowances. That means if a certificate for one quantity unit is obtained from the market and is being "retired" (i.e., deleted), the total CO_2 emissions are reduced by exactly this quantity amount. The opportunity to retire certificates actually exists in the framework of the EU Emissions Trading System. In Germany, the German Emissions Trading Authority (DEHSt) regulates emissions trading. The authority holds a retirement account with the account number DE-230-17-1. If certificates are transferred to this account, they will be withdrawn from circulation (i.e., deleted) by the end of each year. The Centre for European Economic Research [Zentrum für Europäische Wirtschaftsforschung (ZEW)] has opened its own account at the DEHSt (DE-121-2810-0). Furthermore, the purchasing and retiring of the certificates will be attested by a notary public. In summary, if all players have, for example, paid a total of €120 into the climate account, we will buy certificates for about 8 tons of CO_2 (the price per ton is currently at about €15). This equals the emissions of a ride in a Volkswagen Golf (1.4 TSI) one and a half times around the world.

Control questions. If you have finished reading the instructions and do not have questions, please answer the following control questions:

(*a*) Which total amount does each player have to invest into climate protection, on average, in the 10 rounds to evade dangerous climate change (please tick the correct box)? ☐ €O ☐ €12 ☐ €20 ☐ €40 ☐ €120.

(*b*) Please assume that the necessary amount of €120 to evade climate change has been earned and you have invested a total of €16 in the 10 rounds. How much money will you be paid out? My payout is €_____.

(*c*) In how many rounds can the players decide freely about their investments into climate protection (please tick the correct box)? ☐ in 3 rounds ☐ in 5 rounds ☐ in 7 rounds ☐ in 10 rounds.

(*d*) Please refer to the example stated in the Example section for the numbers. What do the balances on Despina's and Metis' private accounts state? Despina's balance states €_____. Metis' balances states €_____.

(*e*) Please refer to the Example section again. How much would the group have to pay into the climate account in the next four rounds in total to abate dangerous climate change (please tick the correct box)? ☐ €12 ☐ €52 ☐ €68 ☐ €120.

(*f*) When do the players state their first declaration of intent, and when can they revise this declaration? First declaration after round: _____. Revision after round: _____.

(*g*) In your first declaration of intent after round 3, you are asked to state how much you want to invest in climate protection in the following seven rounds in total. If you want to invest an average of €2 per round, which amount would you have to state in your declaration of intent (please tick the correct box)? ☐ €2 ☐ €12 ☐ €14 ☐ €20.

(*h*) Are the declarations of intent binding for the investment decisions in the following rounds (please tick the according box)? ☐ Yes ☐ No.

(*i*) Please refer to the Example section again. What do the figures in the left column "Planned climate account" stand for (please tick the correct box)? ☐ Invested amounts of the first three rounds ☐ Planned investments for the last seven rounds ☐ Invested amounts of the first three rounds plus the planned investments for the last seven rounds.

(*j*) Please refer to the example stated in the Example section for the numbers again. Please assume that all players adhere to their declaration of intent ("geplantes Klimakonto"). Would the investments be enough to evade dangerous climate change (please tick the correct box)? ☐ Yes ☐ No.

(*k*) Please assume that the necessary amount of €120 has not been earned. With which probability will you lose the remaining amount on your private account (please tick the according box)? ☐ 10% ☐ 30% ☐ 50% ☐ 70% ☐ 90% ☐ 100%.

If you have answered all control questions, please signal us. We will come to you and check the answers. Once are no remaining questions, the game starts. Good luck!

Supporting Theoretical Analyses

Game Tradeoffs. As noted in the study by Milinski et al. (2), the multiplicity of equilibria in the game makes classification virtually impossible. The game used here is a modified *n*-person stochastic threshold public goods game, with a total of 10 rounds, of which only 7 allow freedom of choice over the three possible actions.

For illustrative purposes, we provide a hypothetical scenario in Table S2. Assume the group has just completed round 9, with an aggregate contribution of €108 (i.e., they are on track). Assume further that four players stick to €2 in round 10, unilaterally bringing the account to €116. If the two remaining players were convinced (e.g., as a result of previous contribution patterns) that only the two of them would consider deviating from the intermediate €2 contribution in the last round, they would be facing the figures in Table S2.

Ultimately, the decision depends largely, in this situation, on the degree of risk aversion and on mutual expectations. We argue that a third driver of behavior should not be overlooked, namely, moral heuristics. In particular, especially if previous departures from symmetrical burden sharing introduced the need and led to altruistic acts by some of the players, inequity aversion might motivate the latter to refuse participation in an unfair outcome, even at a dear cost to themselves and others. In our experimental setting, we expect these situations to arise more frequently in the treatments with initial unequalizing rounds because they are likely to result in greater disparities among players (attributable to the constrained behavior in the early rounds).

Inequity aversion may be a determinant in guiding the decision based on type of scenarios (Table S2). If, for example, a player is risk-aversive but strongly resists disadvantageous inequity [has a high α-parameter, in the terminology of Fehr and Schmidt (4)], he or she will be unwilling to compensate for the actions of the risk-seeker(s).

Let us return to the above example to evaluate how inequity aversion may steer the end result toward successful or unsuccessful coordination. In its absence, a risk-seeking player believing the opponent to be risk-aversive (i.e., placing a high probability on his or her choosing the high-round contribution of €4) might be inclined to take a chance and choose €0 in the last round. Symmetrically, a risk-aversive individual (e.g., the column player), fearing to see the certainty of a gain jeopardized as a result of free-riding, may well opt for contributing €4. In that case, the two contributions would offset each other and €120 would be reached (top right entry in Table S2). This situation is reminiscent of the snow drift game, which differs from the prisoner dilemma game in that unilateral action, although not as desirable as shared cooperation, still provides a benefit to its pursuer (5). However, if risk aversion is dominated by inequity aversion, the column player may choose either the €2 or €0 contribution, if believing the row player to free-ride, thus leading to the highly inefficient outcome represented by the top left and top middle cells. This outcome is highly inefficient because it does not guarantee certainty of success, notwithstanding the substantial contributions, which, on average, are close to €2 per round per player.

Impact of the Computerized Rounds. As discussed above, the players witness three rounds of unavoidable €2 contributions in two symmetrical treatments, whereas in the remaining two asymmetrical treatments, the players undergo three unequalizing rounds resulting in half of the group being wealthier than the remaining half. At the group level, independent of the treatment, the players contribute €36 to the public good before round 4 begins, keeping them on track with respect to the threshold. What is the impact of this mechanism on the attainable game equilibria? First of all, it makes the achievement of the threshold collectively optimal, because, otherwise, the already invested €36 would have been wasted.

At the risk of oversimplifying the complexity of the six-person 10-round game, we present payoff matrices in Table S3, with the aim of highlighting some key characteristics of the game in the study by Milinski et al. (2) and in the present work. The left matrix concerns the former, whereas the center and right matrices summarize, respectively, the outcome of interactions in the symmetrical and asymmetrical games introduced here. For the sake of presentational clarity, we have simplified the analysis by assuming that two subgroups of three players choosing the same strategy form, effectively reducing the type of interactions to those present in the familiar 2×2 formulation. In other words, the three players in each subgroup act identically, as if they tacitly coordinated on the same choices. Moreover, in Table S3, players can only choose between either free-riding in all active rounds (no contributions) or always contributing the intermediate amount of €2 per round.[¶] This simplification allows one to analyze the game as if it were a one-shot game, where people simultaneously reason on the outcome from picking one of two strategies leading to the corresponding group level Nash equilibria (keeping in mind the above discussion on the no longer attainable Nash equilibria).

Comparing the three cases, we notice that when choosing between no contribution and the intermediate contribution in the respective games, best response behavior leads to two pure strategy Nash equilibria, where all players coordinate on either the free-riding or the intermediate €2 strategy, irrespective of which matrix we consider. However, although in the left matrix, both strategies are payoff-equivalent, with the €2 per round equilibrium being a weak Nash equilibrium and the €0 per round equilibrium being strict, in the symmetrical game in the center of Table S3, the intermediate contribution equilibrium is payoff-dominant (and both are strict). Lastly, in the asymmetrical game, the intermediate contribution equilibrium is, again, payoff-dominant, although it is weak, unlike the no-contribution equilibrium, which is strict. This analysis confirms that the games experimentally tested here can be seen as coordination games of the Stag Hunt kind, with the

[¶]Note that although the all fair-sharer equilibrium is present in all three matrices (top left cells), the one in which all players choose the selfish act in each of the 10 rounds (bottom right cell in the first matrix) is not preserved in either of the games introduced here. Put differently, as a result of the introduction of the computerized rounds, the €0 contribution is no longer attainable in the remaining two matrices.

tradeoff between social cooperation and safety being represented by the more rewarding €2 per round strategy vs. the safer €0 per round strategy, which does not require coordination to succeed (6).

Supporting Empirical Analyses

Contribution Trajectories. What is not captured in the treatment-wise comparisons of success rates in public good provision (Fig. 1 and Tables S4 and S7) is the difference in behavior between failing groups, which sheds light on the motivation (or lack thereof) to provide the public good of climate protection. Although in *Base* and *Pledge*, failing groups provided only €70 and €62.7, respectively, failing groups participating in *Base-Unequal* and *Pledge-Unequal* contributed a remarkable €95.5 and €88, despite the lower success rate in the latter two (−30% in *Base-Unequal* with respect to (w.r.t.) *Base* and −10% in *Pledge-Unequal* w.r.t. *Pledge*). This evidence, together with questionnaire analysis, suggests that the role of the asymmetrical endowments is to render coordination more complex. However, the increased failure rate is not simply the result of a decision by a larger proportion of group members to opt for a no-contribution strategy in the hope of high earnings. Many groups in these two treatments clearly tried to reach the €120 threshold until the last rounds, therefore increasing the average contribution relative to the failing groups in *Base* and *Pledge*, which often behaved as if they tacitly agreed on gambling with the probability, attributable to low contributions in the early rounds. In fact 6 (75%) of 8 failing groups in *Base* and *Pledge* combined provided ≤€70, whereas in the corresponding asymmetrical treatments, only 2 (17%) of 12 failing groups provided ≤€70. In other words, the inequality undermined the groups' ability to coordinate effectively on the prevention of simulated climate change damage rather than their motivation, which is actually higher than in symmetrical treatments.

Contribution Dynamics and Role of Pledges. Taking a closer look at *Base-Unequal*, an analysis of the dynamics of contributions provides a perspective on the patterns behind the high number of failures that characterized this treatment. Fig. S3 shows, for all treatments, the instances of €0, €2, and €4 contributions, respectively, in a given round. Note that to have comparable figures, round 4 is not considered in the chart, which instead focuses on contributions in rounds 5 to 7 and rounds 8 to 10.

The trend shaping in *Base-Unequal* between early and later rounds is quite pronounced. No contribution instances increase, on average, by 32%; intermediate contributions decrease by 14%; and high contributions drop by 21% in the last three rounds. This account explains the almost ubiquitous coordination failure among participants. No contribution instances increase over time, whereas both intermediate contributions and high contributions decrease over time, leaving little scope for catching up in the final rounds.

Unsurprisingly, the two treatments characterized by the highest success rate, *Pledge* and *Pledge-Unequal*, owe much of it to the different dynamics, because contributions in round 4 were similar across all treatments. Let us consider *Pledge* first. The 70% success rate is the result of maintaining the number of no contributions as relatively constant, having a high number of intermediate contributions, and compensating the decline of intermediate contributions with a 71% increase in high contributions in the last three rounds.

Let us now take a closer look at the dynamics in *Pledge-Unequal* and *Base-Unequal* because both are subject to three unequalizing rounds at the beginning. Although the number of no contributions in *Pledge-Unequal* is higher in rounds 5 to 7 relative to *Base-Unequal*, the number of selfish acts was reduced to 6.4 in the last three rounds. For what concerns the €2 count, the differences are not stark, because in the six rounds combined, the *Pledge-Unequal* participants chose this contribution level close to 14 times, whereas the *Base-Unequal* participants chose it 16 times. What ultimately proved to be determinant for success was the number of high contributions, which sufficed to offset the no contributions in several instances. We read this as improved coordination stemming from a commitment that, although nonbinding, nevertheless was an important vehicle of intentions among the participants. As noted before, such a "lubricant of coordination" was particularly effective in the presence of inequalities, which presumably increased the complexity of coordination by bringing fairness issues to the table, with potentially contrasting interpretations over the moral obligations stemming from them (Inequality section in *SI Text*). It should be noted that the subjects took the opportunity to express their planned contributions seriously. In *Pledge-Unequal*, for instance, the average contributions are almost identical to the corresponding pledges. Between round 4 and round 10, contributions amounted to €72 and pledges to €71, and in the last three rounds, contributions amounted to €31.8 and pledges to €32.6.

As illustrated in Fig. 2, the pledges were determinant for the success rate. The value −0.0397 of pledge gap in rounds 4–10 in Table S5 means that at the mean of all three independent variables, an increase by €10 in the difference between cumulative contributions and pledges in rounds 4–10 reduces the probability of being in a successful group by about 40%. Similarly, an increase by €10 in the difference between cumulative contributions and pledges in rounds 8–10 reduces the probability of being in a successful group by about 63%.

So far, we have only tangentially discussed contributions in the first active round of play, namely, round 4. Although, as noted above, variation across treatments is limited, an interesting aspect is whether there are marked differences between average round 4 contributions in failing groups with respect to successful groups. The answer is "yes" (as discussed in the main text). In all treatments, success in the entire game is highly linked to contributions in round 4. The 20 groups that were able to coordinate to protect the climate had average individual contributions of €1.9 (corresponding to €11.4 at the group level), whereas the remaining 20 groups had initial individual provisions of €1.2 (corresponding to €7.3 at the group level). We therefore conjecture that the first actions carry an important weight because they signal the members' commitment to taking quantifiable efforts early on. In terms of feasible trajectories to reach the target of €120, this difference is a small burden because it only takes slightly more than one contribution of €4 in the ensuing six rounds to compensate for the gap accumulated in round 4 between successful and unsuccessful groups. However, we argue that this lack of early initiative has deep symbolic value and explains the resulting differences in success rates.

Inequality. We have seen that inequality impeded coordination among the players. Now, we will analyze in more detail how the groups in the asymmetrical treatments *Base-Unequal* and *Pledge-Unequal* handled the inequality and compare the handling between groups that successfully reached the threshold and groups that did not. The successful groups were strikingly effective in eliminating inequality (Fig. 3). Both the rich players and the poor players contributed, on average, €20 to the climate account. Thereby, 92% of the rich players and also 92% of the poor players gave €20 or more. In groups that did not reach the threshold, the poor players paid, on average, €18.17 into the climate account, whereas the rich players gave only €12.83. Thereby, 47% of the poor players but only 17% of the rich players paid €20 or more.[‖] However, the rich players did not completely refuse to invest. The

[‖]If we exclude the groups that abandoned the ship and decided to gamble, and only consider the groups that actually tried (but failed) to reach the target, the differences are even more marked. In these groups, the poor players paid, on average, €21 into the climate account, whereas the rich players gave only €16. Thereby, 83% of the poor players but only 28% of the rich players paid €20 or more.

majority (53%) invested €14 or more. That means they were willing to reduce but not to eliminate inequality. The poor players, on the other hand, were not willing to accept inequality. Obviously, the rich and the poor had different views on what the appropriate contribution is for each type of player. In the end, the persistence in their different viewpoints was crucial and caused the shipwreck of the group. The pledges appeared to be of great help in mitigating these differences, because in the *Pledge-Unequal* treatment, 75% of the groups managed to eliminate inequality and reach the target, whereas in the *Base-Unequal* treatment, only 33% of the groups managed to do so. We come back to this point in the next section, which discusses the questionnaire data.

Questionnaire. After the experiment, subjects were asked to fill out a questionnaire about the motivation for their contribution decisions during the game and their general opinion about climate change (Table S6).

The summary statistics of the players' motivation for their contribution decisions during the game are somewhat complicated, because, on the one hand, we used open questions to elicit the motives and, on the other hand, the motives obviously depend on the respective group performance. The qualitative categorization of responses reveals that the majority of players are primarily motivated by the achievement of the threshold (43%), fairness considerations (18%), material self-interest (15%), and past group performance (14%). Understandably, the poor players in the asymmetrical treatments *Base-Unequal* and *Pledge-Unequal* care more about fairness than the rich players (22% vs. 15%) and more about the past group performance (27% vs. 14%). About 6% of all subjects state that they are particularly motivated by the climate protection realized through the purchase and retirement of the CO_2 certificates. In the final round, the players are primarily motivated by the achievement of the threshold (42%), material self-interest (18%), hopelessness about reaching the threshold (14%), and fairness considerations (11%). The self-reported motives are in line with the actual behavior in the game (e.g., people stating that fairness was the most important reason often contributed €20 to the climate account, whereas people stating that self-interest was their primary motive mostly gave less than €20). The self-reported motives furthermore help us to understand why some groups did not reach the threshold. Comparing the successful groups that reached the threshold and the groups that did not, fairness considerations were more important for the successful groups (23% vs. 13%), as well as the achievement of the target (52% vs. 35%), whereas self-interest (9% vs. 20%) and past group performance (8% vs. 21%) were less important.

To elicit players' fairness perceptions, the subjects in the asymmetrical treatments were asked whether they agree with the following statement, "Those who began in round 4 with a starting capital of €40 should pay more into the climate account in the following seven rounds than the other players." Overall, 76% of subjects agree with that statement, 10% disagree, and 14% neither agree nor disagree. However, there are significant differences between poor and rich subjects. Among the poor players, 90% agree, 5% disagree, and 5% do neither, whereas among of the rich players, only 62% agree, 15% disagree, and 23% do neither. In another question, subjects were asked, "What would you consider a fair average investment for the last seven (active) rounds for those beginning with €40 and for those beginning with €28?" Possible answers include €0, €1, €2, €3, and €4. Almost all the poor players (95%) perceive €3 as the fair amount for the rich players, whereas only 72% of the rich players share this perception. Similarly, only 23% of the poor players perceive €2 as the fair average contribution for the poor players, whereas 42% of the rich players state that this would be the fair amount. These specific amounts (€3 for the rich and €2 for the poor) are relevant because they reflect the application of the different equity principles. To equalize the players' contributions and payments, the rich should contribute €20 in the active rounds (i.e., €3, on average, per round); conversely, if the past actions were to be discounted and only contributions in active rounds mattered, all players (including the poor) would be expected to give €2 in each round.

A determinant of the subjects' willingness to invest in the public good was the presence of individuals who would overcome self-interest considerations. In Table S7, we report the results of regression analysis on the impact of some of the answers in Table S6 on contributions to the public good. Questions 4 and 5 in the former asked subjects to describe the three most important reasons for their investment decisions over the entire game and in the last round, respectively. Having chosen altruistic compensation for free-riders as a motivation for the contribution decision in round 10 positively and significantly explains players' average contributions over all rounds (variable "Altruism round 10" in Table S7, $n = 240$; $P < 0.0001$). Conversely, if individuals were motivated by self-interest, both generally and when deciding the last round contribution, game contributions decreased ($n = 240$; $P = 0.0006$ and $P < 0.0001$, respectively). A similar negative effect arose when the primary motivation for contribution decisions was identified as a belief that the €120 threshold would not be reached both generally and when deciding the last round contribution ($n = 240$; $P = 0.0010$ and $P < 0.0001$ for the variables "Abandon ship" and "Abandon ship round 10," respectively).

Lastly, we visualize the effect of risk aversion as elicited in question 3 on players' overall contributions in Fig. S4; as expected, contributions increase with risk aversion.

1. Ledyard J (1995) *Handbook of Experimental Economics*, eds Kagel JH, Roth AE (Princeton Univ Press, Princeton), pp 111–194.
2. Milinski M, Sommerfeld RD, Krambeck H-J, Reed FA, Marotzke J (2008) The collective-risk social dilemma and the prevention of simulated dangerous climate change. *Proc Natl Acad Sci USA* 105:2291–2294.
3. Fischbacher U (2007) Z-tree: Zurich toolbox for ready-made economic experiments. *Exp Econ* 10:171–178.
4. Fehr E, Schmidt K (1999) A theory of fairness, competition, and cooperation. *Q J Econ* 114:817–868.
5. Kümmerli R, et al. (2007) Human cooperation in social dilemmas: comparing the Snowdrift game with the Prisoner's Dilemma. *Proc R Soc Lond B* 274:2965–2970.
6. Skyrms B (2001) The stag hunt. Presidential address of the Pacific Division of the American Philosophical Association. *Proceedings and Addresses of the American Philosophical Association,* Vol 75, No. 2 (Nov 2001), pp 31–41.

Fig. S1. A player's involuntary €4 contribution in round 1. "Poor" players had to contribute €4 in each of the first three rounds, whereas "rich" players had to contribute €0 in each of the first three rounds.

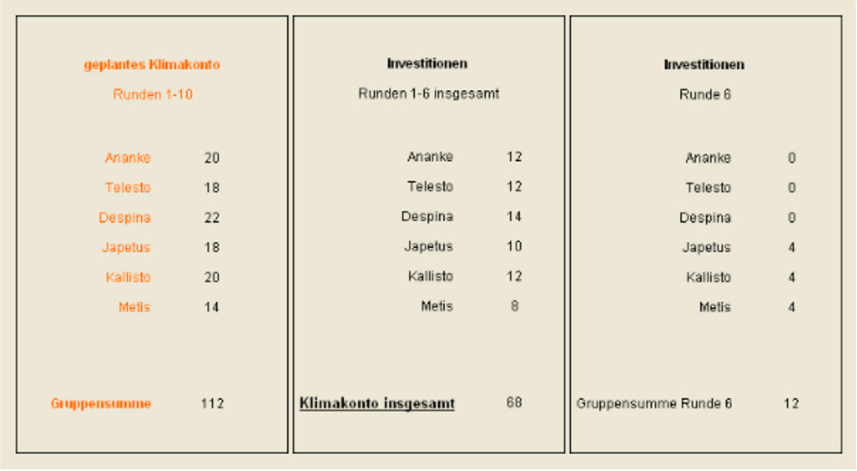

Fig. S2. Feedback after round 6. After each active round, each player received information about the group's contributions if they acted according to the pledges (*Left*), about the amounts contributed up to that round (*Center*), and about investments in the last round (*Right*).

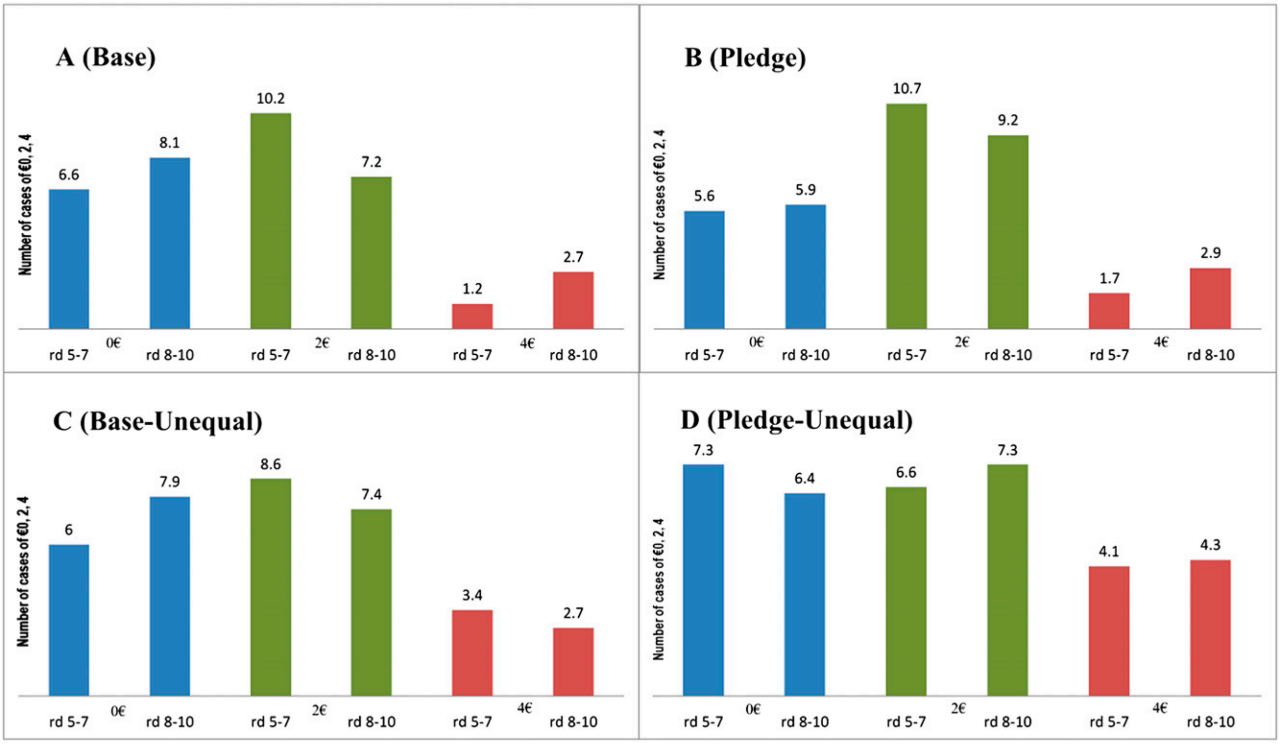

Fig. S3. Contributions in early and late rounds. Amounts invested in rounds 5–7 and 8–10 to protect climate in: *Base* (*A*), *Pledge* (*B*), *Base-Unequal* (*C*), and *Pledge-Unequal* (*D*). rd, round.

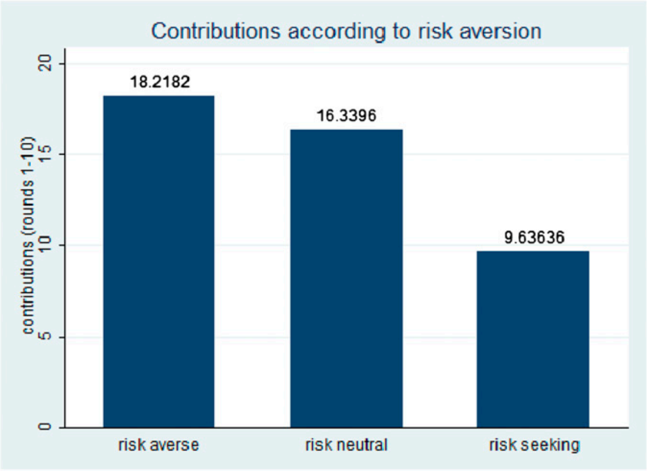

Fig. S4. Mean investment in avoiding simulated dangerous climate change declines when the subjects are more prone to "gambling for global goods."

Table S1. Summary of experimental design

Treatment	Asymmetrical players	Pledge stages	Probability of climate change	No. of subjects
Base	No	No	50%	60
Pledge	No	Yes	50%	60
Base-Unequal	Yes	No	50%	60
Pledge-Unequal	Yes	Yes	50%	60

Table S2. End payoffs (and corresponding final climate account values in parentheses) to the row player given round 9 moves

	€0	€2	€4
€0	11* (116)	11* (118)	22 (120)
€2	10* (118)	20 (120)	20 (122)
€4	18 (120)	18 (122)	18 (124)

Entries on or below the antidiagonal are certain, whereas the starred entries are expected values based on the 50% probability of account loss.

Table S3. A coordination game situation: End payoffs (and corresponding final climate account values in parentheses)

	Fair	Selfish		Fair	Selfish		Fair	Selfish
Fair	20, 20 (120)	10*, 20* (60)	Fair	20, 20 (120)	10*, 17* (78)	Fair	14, 26 (120)	7*, 20* (78)
Selfish	20*, 10* (60)	20*, 20* (0)	Selfish	17*, 10* (78)	17*, 17* (36)	Selfish	14*, 13* (78)	14*, 20* (36)

Selfish refers to the strategy of giving €0 in each of the active rounds (10 rounds in the left matrix and 7 in the remaining two), and Fair refers to the strategy of giving €2 per active round. Although all matrices are based on an initial endowment of €40, in the games introduced here, the endowment before round 4 is either €34 for all players (center matrix) or, alternatively, €28 for "poor" row players and €40 for "rich" column players (right matrix). Payoffs above the antidiagonal are certain, whereas the starred entries are expected values based on the 50% probability of account loss.

Table S4. Probit estimation of treatment effects

Variables	Marginal effects (robust SE)	Marginal effects (robust SE)	Marginal effects (robust SE)	Marginal effects (robust SE)
Base	−0.100 (0.224)	0.320 (0.211)	−0.205 (0.218)	
Pledge	0.108 (0.230)	0.483*** (0.174)		0.205 (0.220)
Base-Unequal	−0.400** (0.187)		−0.479*** (0.168)	−0.318 (0.206)
Pledge-Unequal		0.404** (0.194)	−0.107 (0.229)	0.101 (0.224)
No. of observations	240	240	240	240

The dependent variable is the success of a player's group. Numbers are marginal effects at the mean of the independent variables. Robust SEs are shown in parentheses (clustered at group level). Significance: $^{**}P < 0.05$; $^{***}P < 0.01$.

Table S5. Probit estimation of pledge effects

Variables	Marginal effects (robust SE)
Pledge-Unequal	−0.244 (0.197)
Pledge gap rounds 4–10	−0.0397*** (0.0129)
Pledge gap rounds 8–10	−0.0629** (0.0299)
No. of observations	120

The dependent variable is the success of a player's group. Numbers are marginal effects at the mean of the independent variables. Robust SEs are shown in parentheses (clustered at group level). See Fig. 2 in the main text for a visual representation of the link between success and adherence to pledged contributions. Significance: $^{**}P < 0.05$; $^{***}P < 0.01$.

Table S6. Selected questions and responses from questionnaire (translated from German)

Question		Answer	No.	%
(*i*) Do you agree with the following statement? "Those who began in round 4 with a starting capital of €40 should pay more into the climate account in the following seven rounds than the other players."		Agree	91	75.83
		Disagree	12	10.00
		Neither	17	14.17
(*ii*) Please assume that three players of a group begin in round 4 with starting capital of €40 (because they have not paid anything into the climate account yet), whereas the other three players begin with starting capital of €28 (because they have paid €4 into the climate account in each of the first three rounds).	What would you consider a fair average investment for the following seven rounds for those beginning with €40?	0	2	0.83
		1	2	0.83
		2	30	12.50
		3	190	79.17
		4	16	6.67
	What would you consider a fair investment for the following seven rounds for those beginning with €28?	0	9	3.75
		1	143	59.58
		2	85	35.42
		3	3	1.25
		4	0	0.00
(*iii*) Please imagine the following situation: You have €40. With a probability of 50%, you will lose all €40. You could avoid the risk by giving away €20 of the €40. Would you pay €20 to avoid the risk?		Yes	165	68.75
		No	22	9.17
		Indifferent	53	22.08
(*iv*) Please briefly describe the three most important reasons for your investment decisions in descending order of importance. Possible examples are: Group or own investments in the preliminary round; Cumulated group or own investments starting in round 4; Cumulated group or own investments starting in round 1; Monetary self-interest; Fairness consideration; Achievement of the €120 limit; Adherence to declarations of intent; Other reasons (please state)				
(*v*) What has been your motivation for your investment decision in the last round (round 10)? Please state your three most important reasons in descending order of importance (for possible answers, see previous question).				
(*vi*) If you were to play the game again, would you make different decisions? Please state your three most significant changes in descending order of importance.				
		Σ	240	100.00

Question 1 was asked in the asymmetrical treatments *Base-Unequal* and *Pledge-Unequal* only. Question 2 was asked in all treatments; therefore, it was hypothetical in the symmetrical treatments *Base* and *Pledge,* whereas it was real in the asymmetrical treatments. No responses are provided for open questions 4–6.

Table S7. Linear regression of individual contributions

Variables	OLS Coefficient (robust SE)	Tobit Coefficient (robust SE)
Pledge	1.107 (1.205)	1.110 (1.170)
Base-Unequal	1.169 (0.898)	1.132 (0.880)
Pledge-Unequal	1.237 (1.084)	1.202 (1.071)
Fair contribution (Q2a)	1.068 (0.639)	1.056* (0.622)
Risk seeker (Q3)	−6.686*** (1.357)	−6.815*** (1.382)
Risk neutral (Q3)	−1.614*** (0.546)	−1.614*** (0.535)
Self-interest (Q4)	−2.913*** (0.838)	−2.898*** (0.824)
Abandon ship (Q4)	−4.647*** (1.398)	−5.055*** (1.710)
Self-interest round 10 (Q5)	−4.107*** (0.747)	−4.094*** (0.731)
Abandon ship round 10 (Q5)	−6.328*** (0.855)	−6.330*** (0.833)
Altruism round 10 (Q5)	4.954*** (1.129)	4.927*** (1.104)
Constant	16.11*** (2.337)	16.16*** (2.270)
No. of observations	240	240

The dependent variable is a player's cumulative contributions over rounds 1–10. Tobit is bounded between 0 and 40. Robust SEs are shown in parentheses (clustered at group level). Significance: *$P < 0.10$; ***$P < 0.01$. OLS, Ordinary Least Squares.