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

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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

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

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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.

"poor" 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

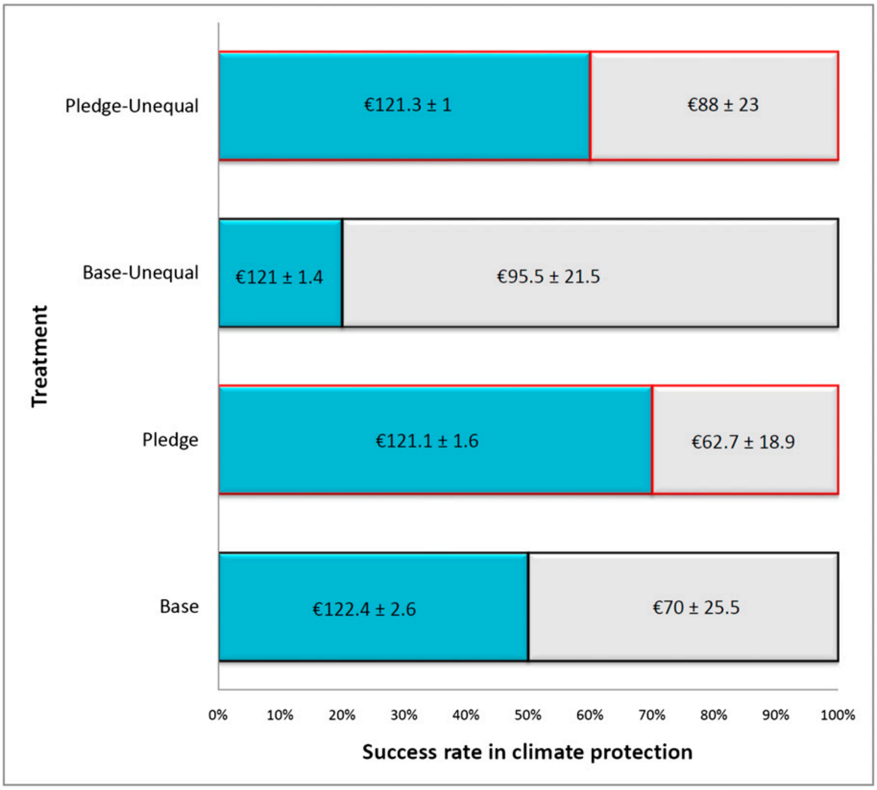

Fig. 1. Success rate in avoiding dangerous climate change. The lower two treatments are symmetrical, and the upper two are asymmetrical. The blue sections of the bars indicate the % of successful groups, whereas the gray sections indicate the corresponding failures (with red contours for the treatments 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*).

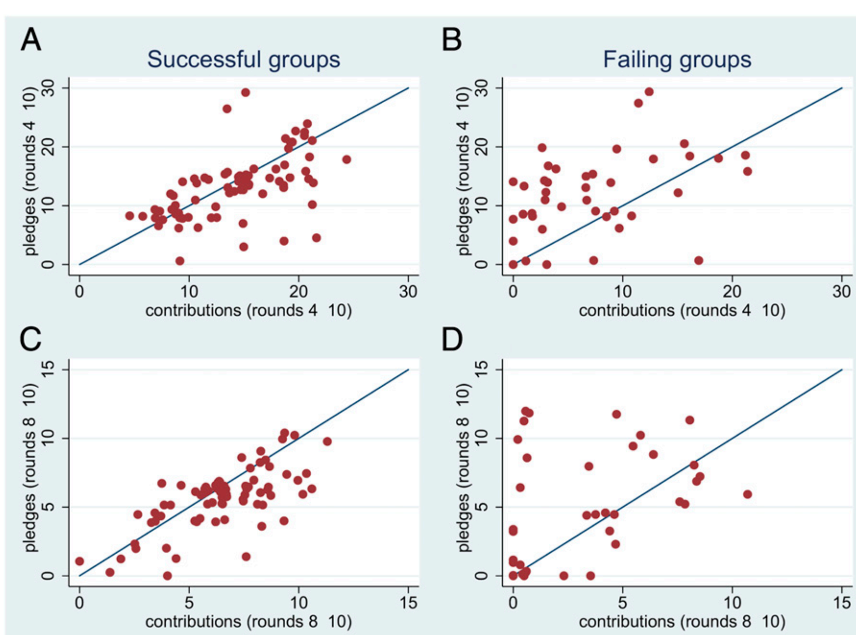

Fig. 2. Departure from announced contributions and its link to success. The probability that a player belongs to a successful group decreases with the contribution-pledge gap, i.e., with the differences between cumulative contributions and the corresponding amounts pledged both early (rounds 4–10, Probit; $P = 0.002$) 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.

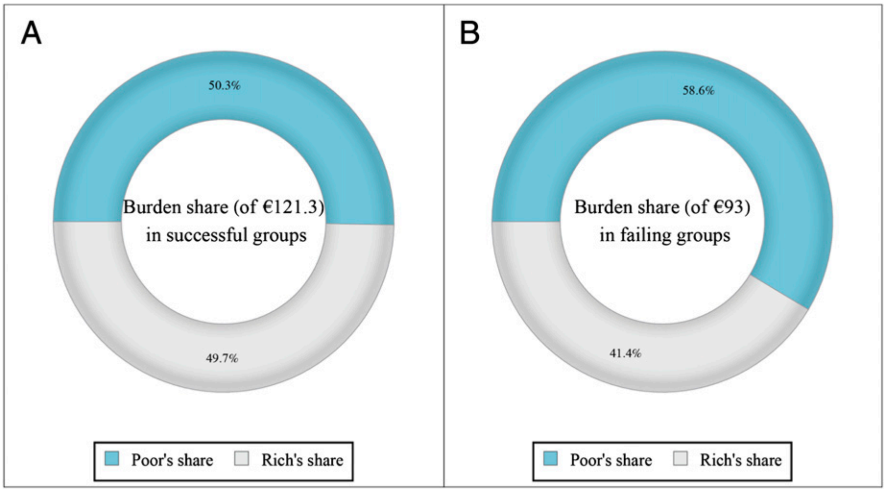

Fig. 3. Relative share of the total contributions taken up by players with different endowments, depending on which group they belong to. (*A*) In successful groups partaking of the treatments with unequal endowments (*Base-Unequal* and *Pledge-Unequal*), the rich compensated the poor by investing more 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.

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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.