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Positive Interactions Promote Public Cooperation

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The public goods game is the classic laboratory paradigm for studying collective action problems. Each participant chooses how much to contribute to a common pool that returns benefits to all participants equally. The ideal outcome occurs if everybody contributes the maximum amount, but the self-interested strategy is not to contribute anything. Most previous studies have found punishment to be more effective than reward for maintaining cooperation in public goods games. The typical design of these studies, however, represses future consequences for today's actions. In an experimental setting, we compare public goods games followed by punishment, reward, or both in the setting of truly repeated games, in which player identities persist from round to round. We show that reward is as effective as punishment for maintaining public cooperation and leads to higher total earnings. Moreover, when both options are available, reward leads to increased contributions and payoff, whereas punishment has no effect on contributions and leads to lower payoff. We conclude that reward outperforms punishment in repeated public goods games and that human cooperation in such repeated settings is best supported by positive interactions with others.

The prisoners' dilemma illustrates the tension between private and common interest. Two people can choose between cooperation and defection. If both cooperate, they get more than if both defect, but if one person defects while the other cooperates, the defector gets the highest payoff and the cooperator gets the lowest. In a one-time prisoners' dilemma game, it is therefore in each person's interest to defect. However, if pairs of people play the game repeatedly, it is no longer obvious that defection promotes the defector's private interest, because today's defection may lead the opponent to defect in the future. Under suitable conditions, such direct reciprocity can support cooperation (1–6). Even if people play different opponents in every round, my opponent tomorrow may condition her choice on my play today. Such indirect reciprocity can also sustain cooperation (7, 8). Direct and indirect reciprocity represent fundamental aspects of human interaction, both in evolutionary history and in

modern life: Repetition is often possible, and reputation is usually at stake.

The public goods game is a prisoners' dilemma with more than two people (9). Typically, there is a choice of how much to contribute to a common pool, which then benefits all participants equally. The maximum payoff for the group is achieved if everyone contributes the full amount, but free riders increase their own payoff by withholding their contribution and still benefiting from the public pool. All of us are engaged in many public goods games, on both large and small scales. For example, reducing CO_2 emissions by driving fuel-efficient cars and minimizing waste is a global public goods game. On a more local level, public goods games include volunteering on school boards or town councils and helping to maintain the roads and fire department in your city, as well as cleaning your dishes at home and doing your share of work at the office.

It has been suggested that costly punishment can uphold cooperation in public goods games (10–12). People are willing to pay a cost for others to incur a cost. Typically, such punishment is directed toward free riders and therefore could be a deterrent for defection (13–15). One problem with punishment is that it generates a social loss by reducing both players' payoffs. This effect, however, could be small if sanctions are used rarely, such that in the long run punishment increases net payoffs by discouraging free riding (16), or if punishments are merely symbolic (17–21). Another

problem is that punishment is sometimes used by free riders against cooperators, either randomly or as an act of revenge (22–25). Moreover, the extent to which punishment is perceived as justified can greatly affect the response of those who have been punished (26). These observations question the proposal that costly punishment is an ideal force for promoting cooperation (12). More generally, the substantial literature emphasizing the beneficial effects of material and symbolic rewards and the negative effects of sanctions on interpersonal relationships (27–31) casts doubt on whether the threat of costly punishment provides the most appropriate incentive for cooperation.

In this study, we demonstrate that it is not costly punishment that is essential for maintaining cooperation in the repeated public goods game but instead the possibility of targeted interactions more generally. In the normal repeated public goods game, if one person lowers his contribution, then I cannot directly reciprocate against this person. I could also lower my contribution, but this action harms everyone in the group. Ultimately, this leads to a decline in cooperation. Therefore, we consider public goods games in which after each round there is also the possibility of targeted interactions with other individuals in the group. One such interaction is costly punishment, but another is costly rewarding, as captured by the standard prisoners' dilemma game. In this scenario, I can reward people who have contributed in the public goods game with cooperation but punish free riders with defection.

In the course of daily life, people are always involved in both public and private interactions. Opportunities exist for mutually beneficial trade, as well as harmful punishment. My behavior toward others is affected by their previous decisions, both in the private and public domain. If I resent my neighbor's gas-guzzling SUV, I could exercise costly punishment by slashing his tires. Conversely, I could be extra helpful to my other neighbor who just bought a low-emission vehicle. Punishment is destructive and carries the risk of retaliation by those who have been punished. This is particularly true in situations where, unlike in most laboratory studies, interactions are not anonymous. Without the cover of anonymity, it seems probable that people would be less inclined to punish and more likely to reward. Here, we ask whether rewards can lead to cooperation in the repeated public goods game.

A total of 192 subjects participated in our study at the Harvard Business School Computer Lab for Experimental Research (32). Subjects

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interacted anonymously via computer screens in groups of four. Subjects were told that they would interact with the same three people for the whole session. We performed one control experiment and three treatments.

In the control experiment, subjects play several rounds of a standard public goods game in groups of four (16 control groups). In each round, subjects receive 20 monetary units and decide how much to contribute to the public pool and how much to keep for themselves. The contributions are multiplied by 1.6 and split evenly among the four group members. Subjects are not told the total number of rounds. For a discussion of end-game effects, see (32).

In the three treatments, each public goods game is followed by a second stage, which allows for responses targeted at each other group member. These targeted interactions have different forms in the three treatments (32). In the first treatment (PN, 10 groups), subjects can punish or do nothing. In the second treatment (RN, 11 groups) subjects can reward or do nothing. In the third treatment (RNP, 11 groups) subjects can choose among reward, nonaction, and punishment.

Figure 1A shows the average contribution to the public goods game in each round. Consistent with previous findings, we observe that the average contribution declines in the control experiment but stays high in the punishment treatment, PN. However, we also observe that the two other treatments, RN and RNP, are equally effective in maintaining cooperation in the public goods game. Therefore, it is not punishment per se that is important for sustaining contributions but rather the possibility of targeted interactions. This option is present in all three treatments but absent in the control experiment.

Figure 1B shows the percentage of the maximum possible payoff achieved in each round. The maximum payoff is obtained for full cooperation in the public goods game, no punishment use in the PN treatment, and full rewarding in the targeted rounds of the RN and RNP treatments. All three treatments in which targeted interactions are possible outperform the control after an initial period of adjustment. We again find that reward works as well as punishment, with no significant difference in percentage of maximum possible payoff between the three targeted treatments.

Figure 1C shows the average payoff in each round, summed over the public goods game and the targeted interaction. In the RN and RNP treatments, there is the possibility of generating additional income during the targeted interactions. Thus, it follows naturally from Fig. 1B that the reward treatments, RN and RNP, generate larger absolute payoffs than the punishment-only treatment, PN. Groups that have the opportunity to reward do better than groups that can only punish. The point we want to make is this: If several targeted interactions can promote cooperation in the public goods game, then those that generate additional positive payoff will result in the best outcomes.

Figure 2 shows the frequency of reward and punishment in each targeted round. We see that both options are used. We also see clear changes in punishment and reward use over time. In the PN and RNP treatments, punishment use decreases over time. In the RN and RNP treatments, reward use increases over time. The latter finding suggests that rewarding is stable and does not decay over time, in contrast to findings in a setting where the possibility for direct reciprocity was limited
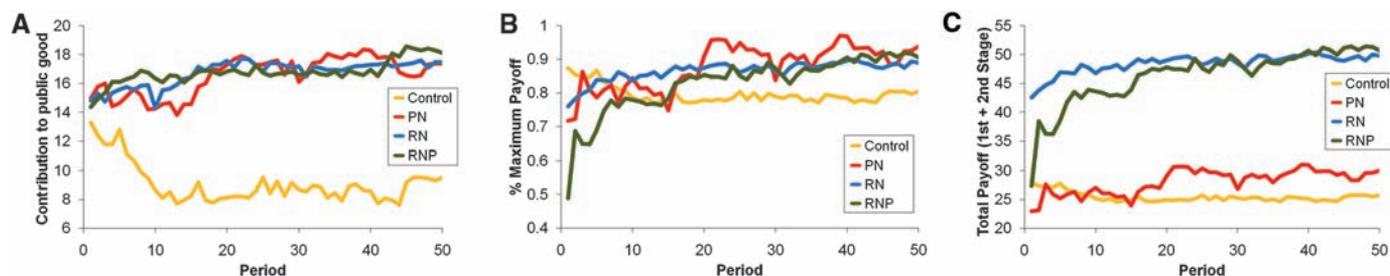
Fig. 1. Mean contribution to the public good (A), percentage of maximum possible payoff (B), and mean payoff (C) over 50 rounds of play in the control (yellow), PN (red), RN (blue) and RNP (green) experiments. All three treatments with targeted reciprocity succeed equally well at increasing contributions and percentage of maximum possible payoff relative to the control, and thus the reward treatments RN and RNP result in significantly higher actual payoffs than the punishment treatment PN. All data are analyzed at the level of the group to account for interdependence of outcomes for members of a given group. (**A**) Sign-rank test comparing contributions in round 1 versus round 50: Control, $P =$ 0.028, decrease; PN, $P = 0.18$, no change; RN, $P = 0.036$, increase; RNP, $P =$ 0.033, increase. (**B**) Rank sum comparing percentage of maximum possible payoff in the second half of the game: PN versus control, $P = 0.013$, PN higher; RN versus control, $P = 0.048$, RN higher; RNP versus control, $P = 0.023$, RNP higher; PN versus RN, $P = 0.67$; PN versus RNP, $P = 0.46$; RN versus RNP, $P =$ 0.40. (**C**) Rank sum comparing mean payoff in the second half of the game: PN versus control, $P = 0.013$, PN higher; RN versus control, $P < 0.001$, RN higher; RNP versus control, $P = 0.001$, RNP higher; PN versus RN, $P = 0.001$, RN higher; PN versus RNP, $P = 0.005$, RNP higher; RN versus RNP, $P = 0.40$.
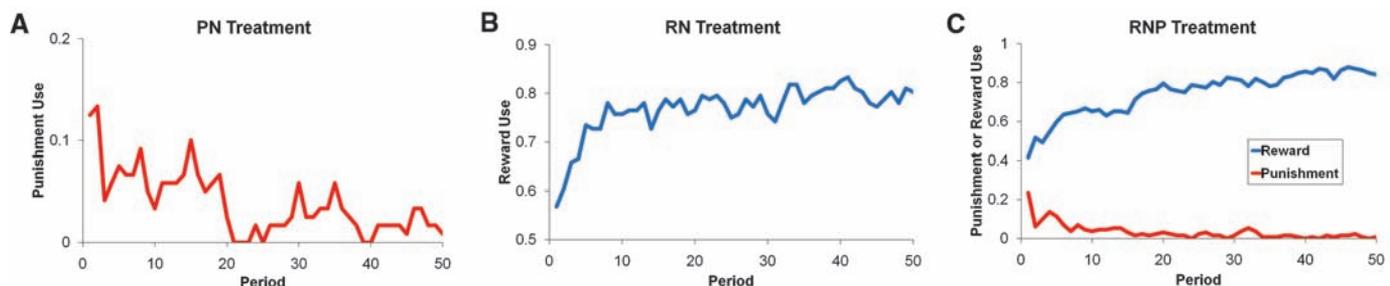

Fig. 2. Frequency of punishment use (red) decreases and reward use (blue) increases over 50 rounds of play in the PN (A), RN (B), and RNP (C) treatments. All data are analyzed at the level of the group to account for interdependence of outcomes for members of a given group. (**A**) Sign-rank comparing punishment use in rounds 1 and 50: $P = 0.12$; comparing rounds 1 to 5 with rounds 46 to 50: $P = 0.073$, decreases; comparing rounds 1 to 10 with rounds 41 to 50: $P = 0.037$, decreases. (**B**) Sign-rank comparing reward use in rounds 1 and 50: $P = 0.018$, increases; comparing rounds 1 to 5 with rounds 46 to 50: $P = 0.033$, increases; comparing rounds 1 to 10 with rounds 41 to 50: $P = 0.075$, increases. (**C**) Sign-rank comparing move use in rounds 1 and 50: R, $P = 0.007$, increases; P: $P = 0.007$, decreases; comparing rounds 1 to 5 with rounds 46 to 50: R, $P = 0.006$, increases; P, $P = 0.004$, decreases; comparing rounds 1 to 10 with rounds 41 to 50: R, $P = 0.006$, increases; P, $P = 0.009$, decreases.

by shuffling player identifiers from round to round (33).

If positive reciprocity alone (RN) and negative reciprocity alone (PN) both increase contributions relative to the control, one might think that putting the two together (RNP) would be best, as found previously in a two-player proposer-responder game (34). However, the RNP setting shows that positive and negative reciprocity cannot be combined in an additive way. The average contribution and percent of maximum possible payoff in RNP are not significantly different from that of RN or PN (Fig. 1). Moreover, the average total payoff in RNP is not significantly different from RN, but is significantly higher than PN.

We can also see that when both options are available, groups that reward more earn higher payoffs while groups that punish more earn lower payoffs (Fig. 3, A and B). It could be that the groups who punished more heavily did so merely because they had the bad luck of containing more free riders, not because they had a greater tendency to punish. However, we see a similar pattern when we examine the probability to punish or reward based on the contribution level in the public goods game (first-order conditional reward and punishment strategies). Groups that are more likely to reward average or above-average contributors achieve significantly higher average contributions (Fig. 3C). Conversely, the tendency to punish low contributors has no effect on contributions (Fig. 3D). As a result, choosing to reward good behavior leads to significantly higher payoffs (Fig. 3E), whereas opting to punish free riders results in marginally lower payoffs (Fig. 3F), because punishing is costly but ineffective in the RNP treatment. When both options are possible, positive reciprocity trumps negative reciprocity for improving contributions in the public goods game and total payoffs.

We have shown that several types of targeted interactions can stabilize contributions in the repeated public goods game. Most previous experiments have focused on punishment and examined situations where subjects cannot track the identity of other group members who punished them. In such settings, typically the groups are changed or the identities of group members are reshuffled in every round. Subjects are often informed about the total amount of punishment they received, but not from whom the punishment came. These designs reduce or eliminate effects of reputation, as well as retaliation by those who have been punished.

Previous studies of reward versus punishment in such settings that limit direct reciprocity have found rewards to be largely ineffective (33–36). In our experiment, however, which is based on repeated interactions where future consequences discipline your actions today, reward is as effective as punishment. We think that this type of truly repeated interaction plays an important role in the study of human behavior. Our ancestors lived in small groups where repeated interactions were common, reputation was often at stake, and the identities of those that chose to punish or

reward were usually known (37). Such concerns are still relevant in today's world, because many of our actions have future consequences. This is particularly true in the context of our most important interactions with family members, friends and co-workers. Thus, although we sometimes find ourselves in anonymous one-time interactions where costly punishment might be more effective than reward, the importance of rewards in repeated interactions should not be overlooked. Moreover, other tools for encouraging cooperation exist beyond monetary punishments and rewards, such as ostracism (19) and appeals to normative values (27). The relative effectiveness of such additional mechanisms merits further study.

Indirect reciprocity settings can also stabilize cooperation in the public goods game (38, 39). Such experiments differ from ours in several ways

and were not designed to directly compare punishment and reward. Moreover, in these studies, subjects are informed about their partner's full history of past play with all previous partners. In our study, we showed that private pairwise interactions, where players do not know what happens in games between others, can still stabilize contributions. It is useful to know that full transparency, which is hard to achieve in the real world, is not necessary for targeted interactions to promote public cooperation.

A common argument for the evolution of costly punishment rests on group selection (40). If group selection is evoked as a mechanism for human cooperation, however, then it is important to note that groups that find positive interactions to maintain cooperation in the public goods game will outperform groups that use costly punish-
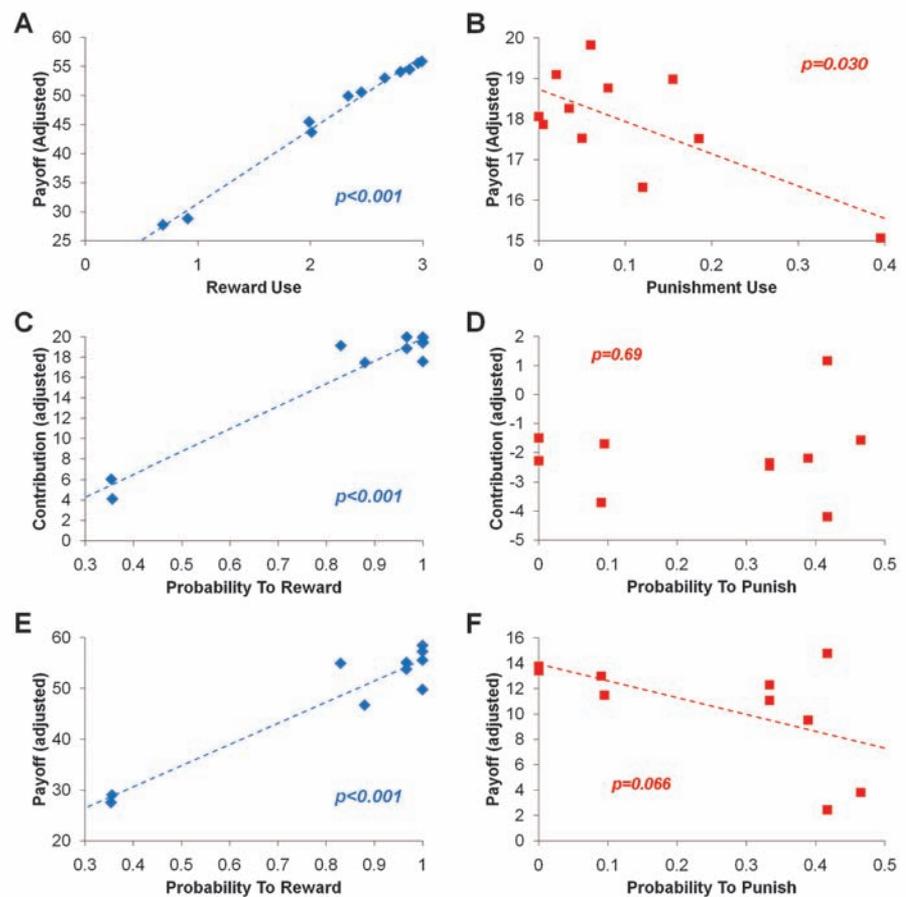

Fig. 3. Mean payoff over the 50 rounds of play in the RNP treatment increases with reward frequency (**A**) (Tobit, slope = 12.7, $P < 0.001$) and decreases with punishment frequency (**B**) (Tobit, slope = −7.9, $P = 0.030$). Mean contribution to the public good increases with the average probability to reward players who contribute equal to or greater than the group average contribution (**C**) (Tobit, slope = 22.2, $P < 0.001$) and is not significantly related to the probability to punish below-average contributors (**D**) (Tobit, slope = 1.1, $P = 0.69$). Mean payoff increases with the probability to cooperate with players who contribute equal to or greater than the group average contribution (**E**) (Tobit, slope = 41.8, $P < 0.001$) and decreases with the probability to punish below average contributors (**F**) (Tobit, slope = −13.2, $P = 0.066$). Data are analyzed at the level of the group to account for the interdependence of outcomes for members of a given group. To correctly visualize the results of a multiple regression analysis, the y axis of each panel is adjusted to account for the variation explained by the independent variable shown in the opposing panel [punishment in (A), (C), and (E) and reward in (B), (D), and (F)]. See (32) for regression tables, axis adjustment details, and further statistical analysis.

ment. Moreover, cross-cultural differences have been observed in antisocial punishment, where low contributors punish high contributors (24). Although antisocial punishment is rare among subjects from the United States or the United Kingdom, it is quite common in countries such as Greece and Oman. Thus, although punishment may eventually improve payoffs in long games using subjects from the United States or the United Kingdom, as in the present study and (16), this is almost certainly not the case in areas where antisocial punishment is common. Instead, antisocial punishment could easily result in significantly lower payoffs.

Although we have documented the effects that bilateral punishment and reward can have on multilateral cooperation, our experiment does not allow us to look at the reverse effect. That is, we do not know whether there is more or less bilateral reward or punishment than there would have been if the subjects had not also been engaged in the public goods game. This aspect of linking together different games has received little attention in the experimental literature and deserves further study.

Sometimes it is argued that it is easier to punish people than to reward them. We think this is not the case. Life is full of opportunities for mutually beneficial trade, as well as situations where we can help others, be they friends, neighbors, office mates, or strangers. We regularly spend time and effort, as well as money, to assist people around us. This assistance can be minor, like helping a friend to move furniture, working extra shifts to cover for an ill co-worker, or giving directions to a tourist. It can also be more important, like recommending a colleague for promotion or speaking out to support a victim of discrimination. These sorts of productive interactions are the building blocks of our society and should not be disregarded.

Our study allows a direct comparison of various kinds of targeted interactions on promoting public cooperation in repeated games. We find that reward is as effective as punishment in maintaining contributions to the public good. However, although punishment is costly for both parties, reward creates benefit and thus results in higher total payoffs. Furthermore, when both punishment and reward are possible, positive reciprocity supersedes negative reciprocity, and punishing results in lower group-level benefits. Although punishment may outperform rewards in one-time anonymous interactions, our findings suggest that positive reciprocity should play a more important role than negative reciprocity in maintaining public cooperation in repeated situations. Imagine that there are groups where people either use punishment or reward to induce public cooperation. Which groups will receive the highest payoffs, and therefore which incentive system is optimal? The results are unequivocal: Rewards produce better outcomes than punishment in repeated settings. These findings highlight the importance of developing opportunities for constructive interactions between individuals, to help us prevent tragedies of the commons.

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Supporting Online Material for

Positive Interactions Promote Public Cooperation

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Supporting Online Material for

Positive interactions promote public cooperation

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This file includes:

1. Materials and Methods

1.1 Methodological details

A total of 192 subjects from Boston area colleges and universities participated voluntarily in a modified repeated public goods game at the Harvard Business School Computer Lab for Experimental Research (CLER). The lab consists of 36 computers, which are visually partitioned. The participants interacted anonymously through the software z-Tree (*S1*) and were from a number of different schools and a wide range of fields of study; it was therefore unlikely that any subject would know more than one other person in the room. Subjects were not allowed to participate in more than one session of the experiment. In all, eight sessions were conducted in February and March 2009, with an average of 24 participants per session. Each session lasted for one hour. In each session, the subjects were paid a $15 show-up fee. Each subject's final score summed over all rounds was converted into dollars at an exchange rate of $1=125 points. The experiments were approved by the Harvard University Committee on the Use of Human Subjects, and written informed consent was obtained from all subjects prior to beginning the experiment.

Each experiment was begun by reading instructions (included in the Supplementary Information). After each public goods game round, the subjects were shown the amount contributed by each group member. In the PN, RN, and RNP treatments, subjects were then asked to choose a private action towards each other group member. At the end of each round, subjects were shown the actions taken towards them by each other group member, and their own payoff in the public goods game and the private round.

1.2 Sample Instructions (RNP setting)

Instructions:

Thank you for participating in this experiment.

Please read the following instructions carefully. If you have any questions, do not hesitate to ask us. Aside from this, no communication is allowed during the experiment.

This experiment is about decision making. You have been randomly matched with 3 other people in the room. Neither of you will ever know the identity of the other. Everyone will receive a fixed amount of $15 for participating in the experiment. In addition, you will be able to earn more money based on the decisions you make in the experiment. Everything will be paid to you in cash immediately after the experiment.

Based on the choices made by you and the three other people in your group, you will receive between $0 and $25, in addition to the $15 show-up amount. Your additional income from the experiment consists of an initial endowment of 50 units plus the sum of all your earnings in each round. The exchange rate is 125 units = $1.

Each member of your group will be assigned a number (1-4) that represents his/her identity throughout this experiment.

The Interaction:

The interaction is divided into rounds. Each round consists of 2 stages.

In **Stage 1**, you have to decide how much you want to contribute to a project that benefits all participants.

In **Stage 2**, you are informed about the contributions of the other participants, and you can then choose actions that influence your and their earnings.

The setup will now be explained in more detail.

Stage 1:

Contribution to the Project: In stage 1 of each round, each person in your group is endowed with 20 units. You have to decide how many of the 20 units you are going to contribute to the project and how many of them to keep for yourself.

The following input-screen for Stage 1 will appear:
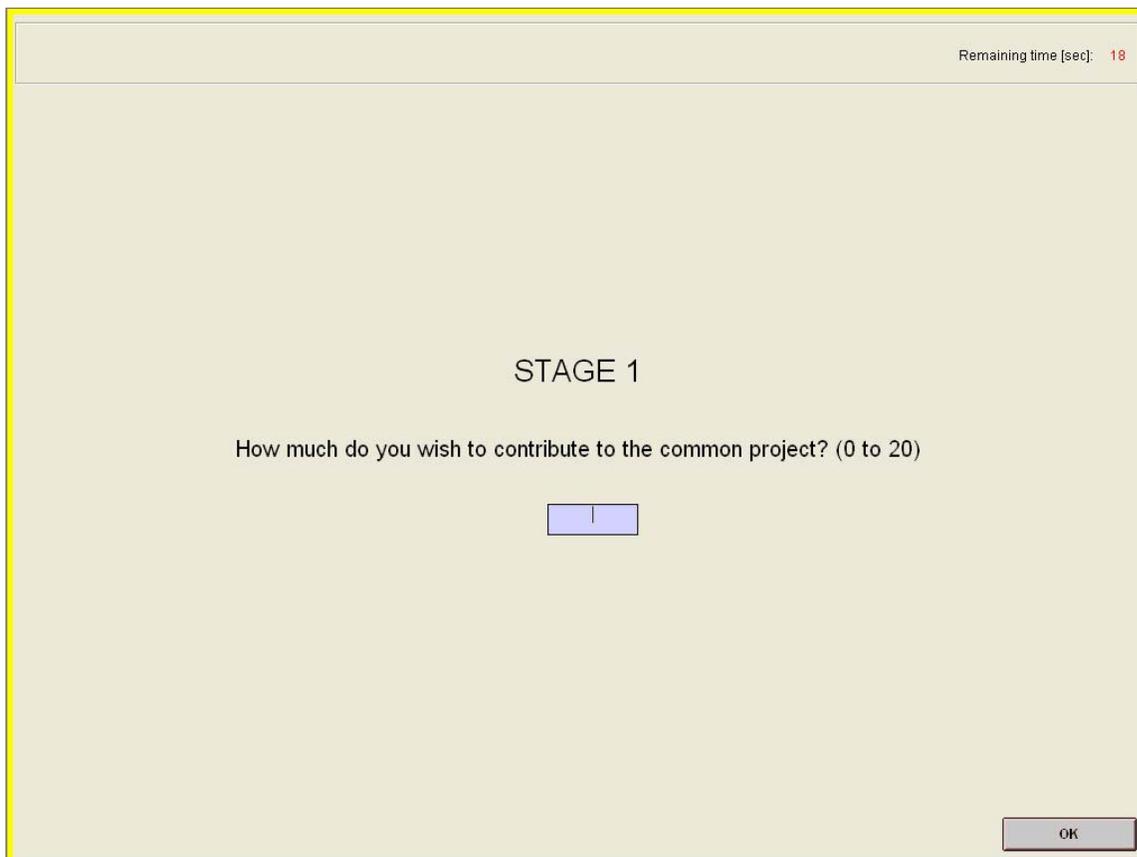
You must enter your contribution within 20 seconds.

Calculation of your income in Stage 1:

The contributions of all 4 players are added up. The total sum is multiplied by 1.6 and then evenly split among all 4 players. Each player gets the same share from the project.

In addition to your earnings from the project, you also receive the units you chose not to contribute.

Thus, **your income in Stage 1** is:

20 – (your contribution to the project) + 1.6 x (sum of all contributions) / 4

Here are two **examples**:

Example 1:
Each player contributes 20 units to the project.
Then each player receives 32 units = 20 – 20 + 1.6 x (20+20+20+20)/4

Example 2:
Three players contribute 20 and one player contributes 0. Then
the contributing players receive   24 units = 20 – 20 + 1.6 x (20 + 20 + 20) / 4
the non-contributing player receives   44 units = 20 – 0 + 1.6 x (20 + 20 + 20) / 4

Stage 2:

In this stage, you interact with each of the three other players individually.

You can see the contributions of all 4 players to the project in Stage 1.

You must decide between one of three possible actions, A, B or C, toward each of the three other players.

If **you choose A** then **you** get **−4 units**, and the **other player** gets +**12 units**.
If **you choose B** then **you** get +**0 units**, and the **other player** gets +**0 units**.
If **you choose C** then **you** get −**4 units**, and the **other player** gets −**12 units**.

The following screen will appear:

You must decide within 60 seconds otherwise random choices will be made.

Calculation of your income in Stage 2: Your income in Stage 2 is the sum of two components:
· the number of units you have received **from your decisions**
· the number of units you have received from **the decisions of the other participants**

To summarize, every round of the experiment has two stages:

Stage 1: **Contribution to the project**
Each participant is endowed with 20 units. You have to decide how many of the 20 units you are going to contribute to the project. The remaining units will be kept in your private account.

Stage 2: **Pair-wise interactions**
You have to choose between one of three actions, A, B or C, toward each of the three other players.

After Stage 1 and 2:

You will see what the others have chosen when interacting with you in Stage 2.
You will see your score from Stage 1 and Stage 2 and your total score for this round.
The following screen will appear:

Then we will move to the next round. Every round consists of the same two stages.
You always interact with the same three people. All players keep their identification numbers.

The interaction will end after an unknown number of rounds. Your behavior has no effect on the number of rounds.

In addition to the $15 show up fee, your income from the experiment consists of an initial endowment of 50 units plus the sum of all your earnings in each round. The exchange rate is 125 units = $1.

2. Supporting analyses

2.1. Private interaction payoff matrices

In the PN treatment's targeted round, subjects can punish (P) or do nothing (N). Punishment means paying a cost of 4 MUs for the other person to lose 12 MUs. This results in the following payoff matrix, where the row player's payoff is shown:

	P	N
P	-16	-4
N	-12	0

In the RN treatment's targeted round, subjects can reward (R) or do nothing (N). This is equivalent to cooperating or defecting in a standard Prisoner's Dilemma game. Reward means paying 4 MUs for the other person to receive 12 MUs. This results in the following payoff matrix:

	R	N
R	8	-4
N	12	0

In the RNP treatment's targeted round, subjects can choose between reward (R), non-action (N) and punishment (P). This results in the following payoff matrix:

	R	N	P
R	8	-4	-16
N	12	0	-12
P	8	-4	-16

2.2 End-game effects: reputation concerns versus purely pro-social preferences

While costly punishment has received much attention in recent years, our results suggest that the possibility of reciprocal actions more generally is the essential factor for promoting cooperation in repeated game. As opposed to measuring purely pro-social preferences, we study the ability of reciprocity concerns to induce pro-social behavior. Because contributions are motivated by a concern for the future, end-game effects (*S2*) are often observed, where cooperation drops steeply when subjects know the game is in its final round (*S3-S5*). In the real world, however, typically one does not know if there might be another interaction and therefore we feel that such end-game effects are less relevant.

2.3 Contribution, payoff, reward and punishment by group

Examining the behavior of each group gives insight into the dynamics of the different settings (Figure S1). Of the 16 groups in the control experiment, four successfully achieve full contribution without any means of targeted interaction. Another seven groups maintain an intermediate level of contribution throughout, and the final five groups see complete breakdown of cooperation, with average contribution dropping to 0 and never having a consistent increase.

In the PN treatment, one group quickly reaches full contribution without punishing, and this cooperation is maintained with minimal punishment use (only five punishments over the 50 rounds of play). Seven groups achieve full contribution through punishment use in the first few rounds to establish cooperation, and/or subsequent spats of punishment when free-riding begins to appear. Two groups fail to achieve full contribution despite significant punishment use.

In the RN treatment, four groups successfully reach full contribution in the public goods game and full cooperation in the targeted interaction. Four more groups converge on full contribution in the public goods game and reach high, but not full, levels of targeted cooperation. Thus full cooperation in the targeted round is not needed to maintain full contribution in the public goods game. Two groups maintain intermediate levels of cooperation in both the public and targeted interactions throughout. Interestingly, in the one group where public cooperation fails, there is still consistent targeted cooperation in three out of the six player pairings. In no group is the average level of targeted cooperation below 50%.

In the RNP treatment, eight groups reach full public contribution and full targeted cooperation with minimal punishment use (5% or less). One group reaches full public contribution, but maintaining high contributions requires persistent punishment across the 50 rounds of play. Another group quickly drops to zero contribution, but after 40 rounds, an increase in targeted cooperation succeeds in restoring public contribution. Only in one group do contributions stay consistently below ten, despite non-negligible use of targeted cooperation and punishment.

Figure S2 shows the average payoff summed over the public goods game and the targeted interaction for each group. The minimum and maximum payoffs in the control and PN are very similar. However, the lowest scoring group in RN earned more than the highest scoring group in PN. Again, reward clearly leads to better outcomes than punishment in the repeated public goods game.
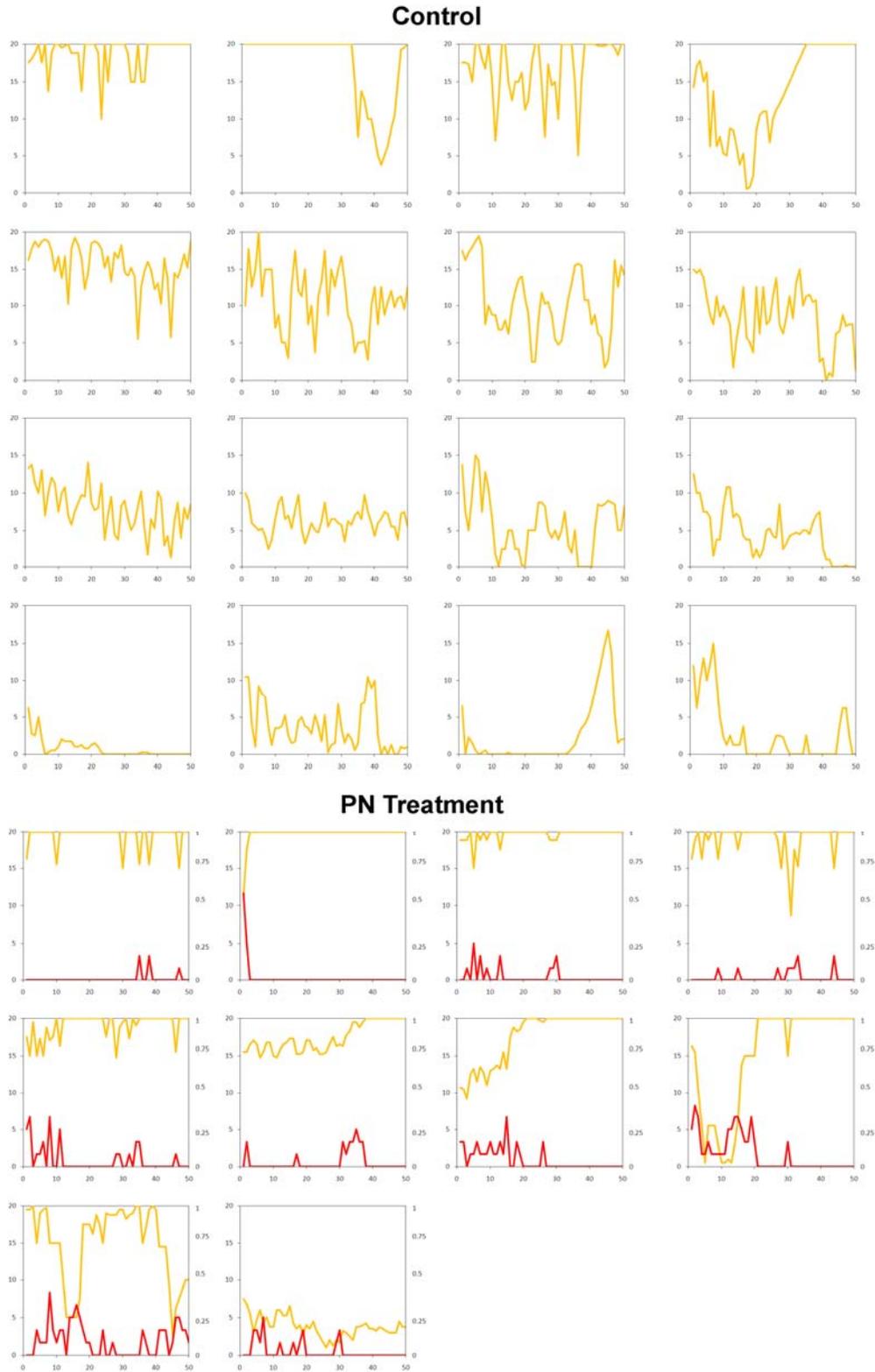
Control

PN Treatment

Figure S1. Contribution (yellow, 0-20), punishment (red, 0-1) and reward (blue, 0-1) dynamics by group over the 50 periods of play.
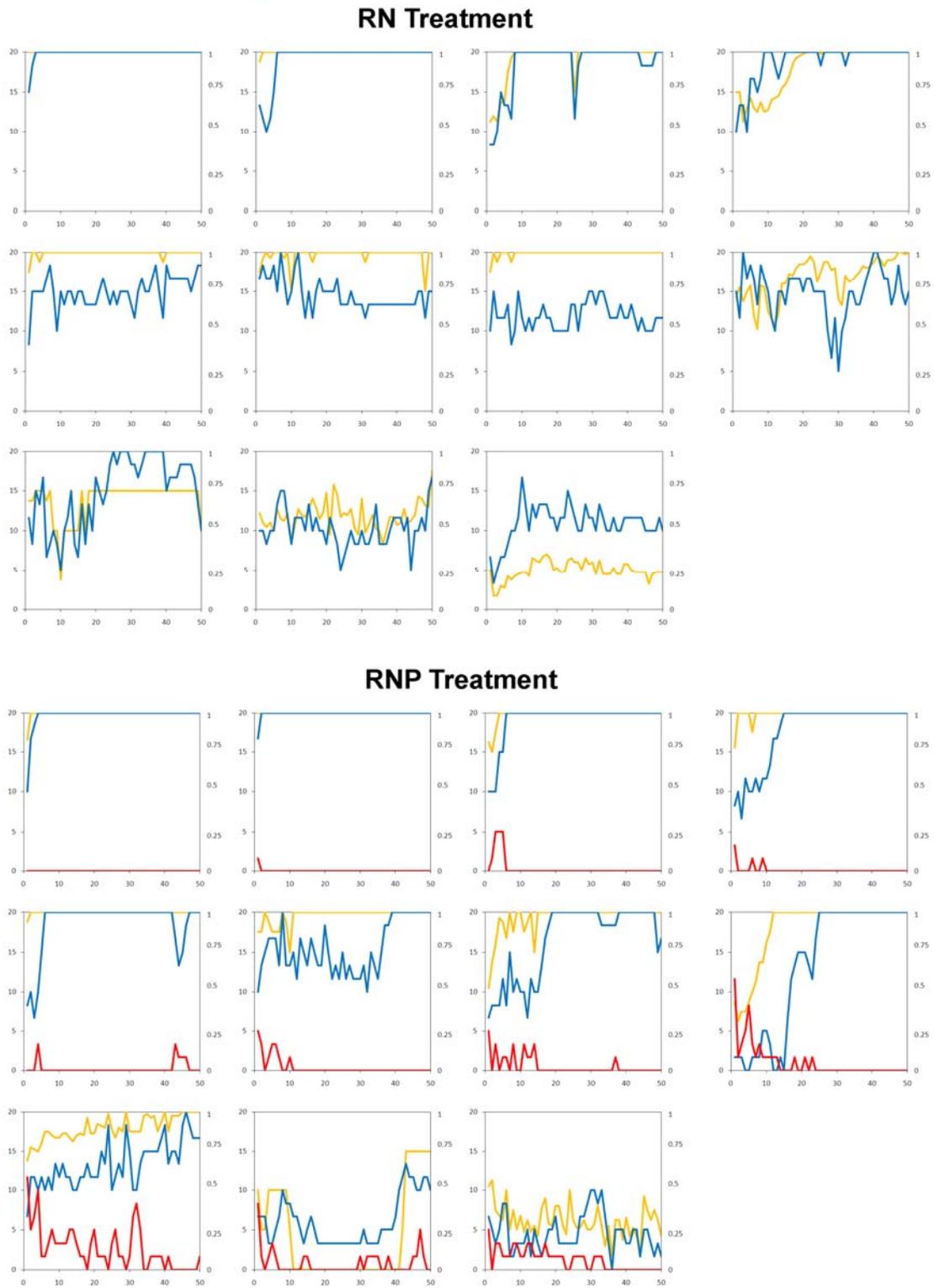
RN Treatment

RNP Treatment

Figure S1 (continued). Contribution (yellow, 0-20), punishment (red, 0-1) and reward (blue, 0-1) dynamics by group over the 50 periods of play.
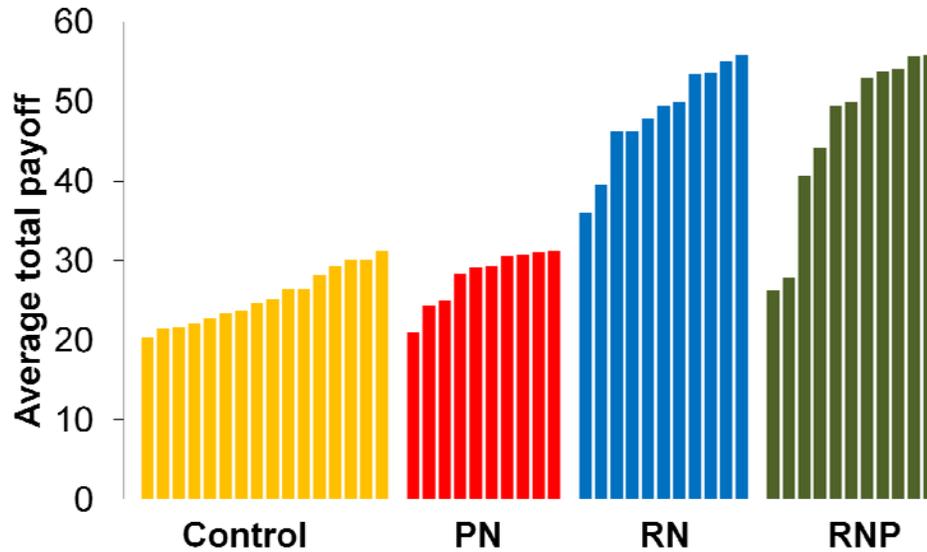
Figure S2. Average payoff summed over the public goods game and targeted interaction for each group.

2.4 Withholding reward as a form of punishment

Both punishment and reward are forms of reciprocity, which allow subjects to create relatively positive or negative outcomes. Thus, the distinction between the two actions is more subtle than it may seem. Denying cooperation in the Prisoners' Dilemma is effectively a form of punishment; indeed, that is the conventional name for such a phase in the literature on repeated games. The possibility for denial of reward based on public goods game contribution can create 'selective incentives' (S6), or benefits which only accrue to active contributors, to overcome the free-rider problem. Similarly, ostracism can sometimes function not as a costly punishment, but rather as a denial of reward. It may be that humans primarily punish each other by withholding rewards in this manner rather than by taking outright damaging actions, but as of yet we are not aware of experimental evidence that speaks directly to the issue. Withholding a costly reward is less aggressive than executing a costly punishment, and may thus damage continuing relationships less. If this conjecture is true, then the presence of the public goods game should not have much of an adverse effect on behavior in the Prisoners' Dilemma game.

2.5 Further statistical analysis of relationship between contribution, payoff, reward and punishment

As shown in the main text Figure 3, rewarding improve outcomes in the RNP treatment while punishment does not. Here we present further analysis of contribution and payoff as functions of probability to reward and punish. Note that one RNP group contributed fully in every period and never had the possibility to punish a below average contributor, and thus this group is not included in the analysis. Tables S1, S2 and S3 present the regression models for the plots shown in Figure 3. Tobit regression is used because the dependent variables are bounded, contribution

Table S1. Payoff versus reward and punishment use (Figure 3A,B)

	Coeff.	Tobit regression, bounded 0-20		OLS regression with robust SEs	
		t	p-value	t	p-value
Reward frequency	12.72	28.69	<0.001	24.43	<0.001
Punishment frequency	-7.88	-2.57	0.030	-2.95	0.018
Intercept	18.68	15.28	<0.001	12.5	<0.001
Observations (Groups)	11				

Dependent variable: Average payoff.

Table S2. Contribution versus reward and punishment probabilities (Figure 3C,D)

	Coeff.	Tobit regression, bounded 0-20		OLS regression with robust SEs	
		t	p-value	t	p-value
Probability to reward average or above average contributors	22.22	11.93	<0.001	13.29	<0.001
Probability to punish below average contributors	1.07	0.41	0.690	0.38	0.713
Intercept	-2.35	-1.56	0.158	-1.57	0.162
Observations (Groups)	10				

Dependent variable: Average contribution in the public goods game.

Table S3. Payoff versus reward and punishment probabilities (Figure 3E,F)

	Coeff.	Tobit regression, bounded 0-20		OLS regression with robust SEs	
		t	p-value	t	p-value
Probability to reward average or above average contributors	41.77	9.38	<0.001	18.01	<0.001
Probability to punish below average contributors	-13.24	-2.12	0.066	-1.97	0.089
Intercept	13.96	3.86	0.005	8.09	<0.001
Observations (Groups)	10				

Dependent variable: Average payoff.

between 0 and 20, payoff between 0 and 56. As Tables S1, S2 and S3 show, OLS with robust standard errors gives equivalent results.

To correctly display the relationships described in tables S1-S3, the y-axis of each panel in Figure 3 is adjusted to take into account the variation explained by the term of the multiple regression not shown. For example, consider Figure 3A. The regression model in Table S1 shows that

$$Payoff = 12.72 * (Reward\ frequency) + (-7.88) * (Punishment\ frequency) + 18.68 \qquad (1)$$

In Figure 3A, payoff is shown as a function of reward use. Equation 1 can be rearranged to describe the relationship between payoff and reward frequency as follows:

$$Payoff - (-7.88) * (Punishment\ frequency) = 12.72 * (Reward\ frequency) + 18.68 \qquad (2)$$

Therefore, to correctly visualize the effect of reward frequency on payoff, the y-axis of Figure 3A shows *Payoff – (-7.88)*(Punishment frequency)*. Similarly, the y-axis of Figure 3B shows *Payoff – (12.72)*(Reward frequency),* Figure 3C shows *Contribution – (1.07)*(Probability to punish)*, Figure 3D shows *Contribution – (22.22)*(Probability to reward)*, Figure 3E shows *Payoff – (-13.24)*(Probability to punish)*, and Figure 3F shows *Payoff – (41.77)*(Probability to reward)*.

We now provide additional analysis of the relationship between contribution, payoff and the probability to reward average or above average contributors. First we show that the correlation between average contribution and probability to reward remains highly significant when using quantile regression, which is less sensitive to outliers (slope=21.3, p=0.001), as does the relationship between payoff and probability to reward (slope=43.7, p=0.004). Second, we strengthen the causal link between probability to reward and higher contributions and payoffs. It could be that the two groups which do poorly are less inclined to cooperate both in the public goods game and in the private round. To demonstrate that baseline prosociality is not driving the relationship between contribution/payoff and reward, we include first round contribution as a control in the multiple regressions. We find that probability to reward remains highly significant, both as it relates to contribution (slope=18.7, p<0.001) and payoff (slope=34.7, p<0.001). This again remains true when using quantile regression, both for contribution (slope=17.8, p=0.023) and payoff (slope=32.2, p=0.035). Moreover, we find no significant relationship between probability to reward and first round contribution (slope=0.03, p=0.18). This shows that rewarding behavior is not driven by the same factor as contribution behavior, and suggests that the tendency to reward helps sustain contribution over time.

2.6 Private round strategies

There are noteworthy differences in the way subjects use cooperation and punishment (Fig S3). In the PN treatment, below average contributors are more likely to be punished than average contributors (Sign-rank, p=0.005) or above average contributors (Sign-rank, p=0.005). Interestingly, above average contributors are also more likely to be punished than average contributors (Sign-rank, p=0.011). Yet there is no significant variation in the probability to receive punishment as a function of the absolute public goods game contribution in the PN

treatment (Sign-rank, p>0.10 for all comparisons). In the RN treatment, a public goods game contribution below the group average is less likely to receive cooperation in the Prisoners' Dilemma than an average or above average contribution (Sign-rank: Below average vs average, p=0.011; Below average vs above average, p=0.005). High absolute as well as high relative contributions are important for eliciting reward in the RN treatment. Only contributions between 16 and 20 are more likely to receive cooperation than defection in the Prisoner's Dilemma (Sign-rank: contribution 0 to 5, p=0.87; contribution 6 to 10, p=0.50; contribution 11 to 15, p=0.44; contribution 16 to 20, p=0.005). In the RNP treatment, we see a similar pattern to the RN and PN treatments. Below average public goods game contributions are less likely to receive cooperation than average or above average contributions (Sign-rank: Below average vs average, p=0.007; Below average vs above average, p=0.028), and more likely to receive punishment (Sign-rank: Below average vs average, p=0.011; Below average vs above average, p=0.008). Cooperation depends on absolute contribution, as in the RN treatment. Contributions of 0 to 5 or 6 to 10 less likely to receive cooperation than defection (Sign-rank: contribution 0 to 5, p=0.011; contribution 6 to 10, p=0.033), contributions of 11 to 15 are equally likely to receive cooperation or defection (Sign-rank, p=0.40), and contribution of 16 to 20 are more likely to receive cooperation than defection (Sign-rank, p=0.006). Punishment, however, does not differ significantly with absolute contribution, as in the PN treatment (Sign-rank, p>0.10 for all comparisons). Errors bars indicate standard error of the mean. All data are analyzed at the level of the group to account for interdependence of outcomes for members of a given group.

To summarize, those who contribute less than average to the public good in the PN and RNP settings are more likely to be punished, regardless of the actual amount contributed. Punishment is determined only by the relative contribution, not by the absolute contribution (as in (*S7*)). In the RN and RNP settings, however, a high actual level of contribution is required to receive cooperation. In addition, people whose contribution matches the group average are most likely to receive cooperation. Thus both relative and absolute contribution levels affect cooperation decisions. This creates an incentive for all group members to contribute fully in the presence of possible rewards. These findings are consistent with previous evidence from proposer-responder games, where rewards are relatively ineffective in eliminating the worst behaviors, but relatively effective in encouraging the best behaviors (*S8*).
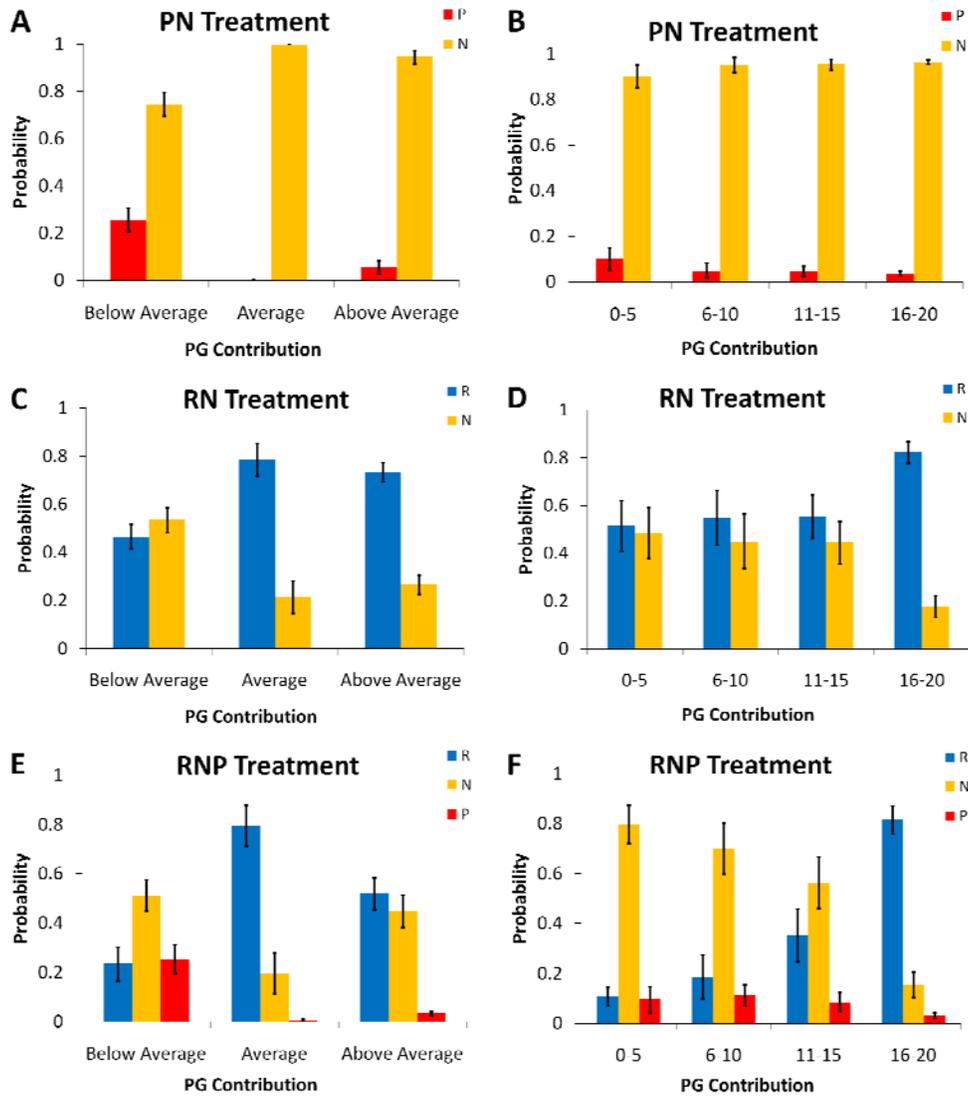
Figure S3. Cooperation is typically directed at high absolute contributors, whereas punishment is directed at low relative contributors regardless of their absolute contribution. The probabilities of various targeted responses are shown depending on the recipient's contribution in the preceding public goods game. Contributions relative to the group average are used in A, C, and E, while absolute contributions are used in B, D, and F. Error bars indicate standard error of the mean.

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