



Munich Personal RePEc Archive

The effects of punishment in dynamic public-good games

Özgür Gülerk and Bettina Rockenbach and Irenaeus Wolff

University of Erfurt, CEREB

15. March 2010

Online at <http://mpa.ub.uni-muenchen.de/22331/>

MPRA Paper No. 22331, posted 26. April 2010 07:29 UTC

The effects of punishment in dynamic public-good games[§]

Özgür Gürer^a, Bettina Rockenbach^a, Irenaeus Wolff^a

^a *University of Erfurt / CEREB, Nordhäuser Straße 63, 99089 Erfurt, Germany*

Abstract:

Considerable experimental evidence shows that although costly peer-punishment enhances cooperation in repeated public-good games, heavy punishment in early rounds leads to average period payoffs below the non-cooperative equilibrium benchmark. In an environment where past payoffs determine present contribution capabilities, this could be devastating. Groups could fall prey to a poverty trap or, to avoid this, abstain from punishment altogether. We show that neither is the case generally. By continuously contributing larger fractions of their wealth, groups with punishment possibilities exhibit increasing wealth increments, while increments fall when punishment possibilities are absent. Nonetheless, single groups do succumb to the above-mentioned hazards.

Keywords: Public good; Dynamic game; Punishment; Endowment endogeneity; Poverty-trap; Experiment

JEL: C73; C91; H41

1 Introduction

Cooperation in social-dilemma situations is a central aspect of life on every scale of human interaction, be it for the purpose of hunting for commonly-shared food, voting under democratic regimes, or preventing climate change from making human life impossible on our planet. The critical issue in each

[§]We would like to thank the research group led by Urs Fischbacher as well as seminar audiences at the University of Erfurt for their helpful comments. We gratefully acknowledge the financial support by the DFG through research grant RO 3071.

of these situations is that, although it is socially beneficial to spend one's private resources on fostering the common goal, individual maximization of resources calls for free-riding on others' cooperative efforts (Robyn M. Dawes, 1980). Studying this issue is particularly important in light of the fact that being involved in a social dilemma is not a once-in-a-life-time experience, but occurs, in various disguises, on an everyday basis. Often today's contribution capabilities depend on past behavior. Financial or physical resources may be low due to past excessive unilateral cooperation. Having taken the costs of emission reduction in the heating system of one's house reduces the financial capabilities in future social dilemmas. Being hurt after showing civil courage lowers the future income possibilities during times of recovery. *Ceteris paribus*, having been a free-rider in past situations provides a healthy and financially well-equipped starting point for future actions. In the limit, past providers may not be *able* to contribute in the future due to excessive free-riding by others, while free-riders accumulate resources on their private accounts.

Although there is a considerable literature on cooperation in social dilemmas (cf., e.g., the reviews in Ernst Fehr and Urs Fischbacher, 2003; or Simon Gächter and Benedikt Herrmann, 2009), surprisingly little is known about its dynamic aspects. In this paper, we experimentally study a linear public-good game in which a subject's provision ability today depends on the subject's and her group members' behavior in the past. Additionally, we allow for the possibility of costly peer-to-peer punishment with a convex punishment technology that is similar to that of Fehr and Gächter (2002) for low values of assigned punishment points.¹ The distinctive feature of our design is the endogeneity of players' contribution capabilities. Instead of providing subjects with (new) endowments in every round they play, they receive an initial endowment on their wealth account and subsequently play with whatever is currently on that account. Consequently, their payoff does not consist of the

¹In introducing a convex punishment technology, we follow the example of studies like Fehr and Gächter (2000); Laurent Denant-Boemont, David Masclet, and Charles Noussair (2007); or Nikos Nikiforakis (2008). Convex punishment technologies have also been used in other areas of economic research such as the law-and-economics literature, e.g., Dhammika Dharmapala and Nuno Garoupa (2004).

sum of period payoffs, but it is given by the final amount on their wealth account.²

The structure of the game has a number of interesting implications. First of all, it puts all the weight on the long run, which is another feature that sets us apart from earlier studies of dynamic elements in the provision of public goods. Notably, this leads to incentives for cooperation even in the absence of a punishment mechanism if at least a fraction of the players is motivated by social considerations. On the other hand, the introduction of a punishment mechanism could have devastating effects if future contribution capabilities are determined by present behavior, especially because early punishment has been shown to be particularly strong in experimental studies of peer-punishment mechanisms (cf., e.g., Fehr and Gächter, 2000; Özgür Gürerk, Bernd Irlenbusch, and Bettina Rockenbach, 2006; or Martin Sefton, Robert Shupp and James Walker, 2007). Alternatively, potential punishers, being aware of this hazard, might refrain from sanctioning other group-members. As a consequence, play in the game with and without the punishment mechanism might not differ.

We find that players do punish, leading to an initial disadvantage of groups with a punishment possibilities as compared to groups that do not dispose of such possibilities. However, groups with punishment possibilities are able to keep players' contributed fractions of their current wealth at a constant level, whereas in the sanction-free environment, these fractions exhibit the typical declining trend. Interestingly, we do not observe any significant differences in the absolute level of public-good contributions at any point in time, which marks a stark contrast to earlier studies of public-good provision.³ However, with punishment levels falling over time, wealth levels in the groups having punishment opportunities are able to catch up with those in the groups without. In contrast to the latter, average wealth

²An interesting related study is that of Edward Buckley and Rachel Croson (2006) who analyse the effect of information about the group members' accumulated wealth levels on contribution decisions as well as the effect of different endowments. In their study, neither different endowments nor heterogeneity in accumulated wealth leads to differences in subjects' contributions.

³Cf., e.g., Fehr and Gächter (2000); or Ernesto Reuben and Arno Riedl (2009) for a game with heterogeneous endowments.

levels in the former exhibit an increasing growth path, such that significantly higher wealth and, consequently, contribution levels seem to be a question of an extension of the time horizon by a small number of rounds.

Having discussed the distinctive features of our study, their potential implications, and our main results, let us review the related literature. There is a substantial theoretic literature on repeated social-dilemma games with earlier play influencing later distributions of different (player) types in evolutionary settings.⁴ However, to the best of our knowledge, experimental studies focusing on dynamics in social dilemmas are surprisingly limited. Noussair and Cindy Soo (2008) study public-good provision when the group's past cooperation level influences each member's current marginal per-capita return of provision. This resembles a situation in which players' abilities to contribute to a public good is unrelated to the payoff stemming from it, but the more cooperative the group has been in the past the higher is the return from future cooperation. In their setting, contribution levels generally do not exhibit the usual falling trend except for a minority of the groups. Abdolkarim Sadrieh and Harrie A. A. Verbon (2006) consider a situation in which a group member's benefit from the public good depends on the player's current wealth. This setup is well-tailored to their focus on inequality and situations prone to the accentuation of this inequality. Their findings are surprising in that subjects' propensity to cooperate is not affected by the degree of inequality induced. In contrast, in a control treatment that does not involve a dynamic component, induced inequality has a positive effect on cooperation. They conclude that subjects' fairness concerns seem to be 'crowded out' by the introduction of the dynamics. Finally, Gächter, Stefan Grosse, and Rockenbach (2009) study dynamic public-good provision in a setting in which the players' endowment in period t is determined by the player's payoff in period $t-1$. In contrast to our study, however, final payoffs are still given by the sum of all period payoffs. Unlike in the study of Nous-

⁴For examples of the evolutionary settings, cf. e.g. Peter J. Richerson and Robert Boyd (2005) and the many references cited therein. For a game-theoretic treatment of a differential-game dynamic public good, see Chaim Fershtman and Shmuel Nitzan (1991). Anat R. Admati and Motty Perry (1991) analyse a two-player step-level public good with alternating contribution stages.

sair and Soo (2008), groups in the main treatment of the study by Gächter et al. (2009) tend to do worse than those in any of their ‘non-dynamic’ control treatments. In particular, this holds for groups in which the endowment history was induced corresponding to the history of a randomly chosen ‘twin group’ in the main treatment. This latter finding seems to be in line with the earlier findings of Sadrieh and Verbon (2006) reported above.

In the remainder of this introduction, let us shortly present the structure of our paper. We introduce the game-theoretic model underlying our experimental setting in section 2. We will lay out the standard game-theoretic solution to the game and point to a number of notable differences of our dynamic setting to the usual static setting, where “dynamic” and “static” are meant to refer to endogenous and exogenous endowment determination, respectively. We will further discuss the effects social preferences would have on our predictions. Finally, we will use two benchmark scenarios as our research hypotheses to span the range of possible outcomes. In section 3, we present the experimental procedure and design, followed by the presentation of our results in section 4. Section 5, finally, winds up with a discussion of our findings and a pointer to the relevance of our benchmark scenarios.

2 Game-theoretic model

For our investigation, we implement two different games, the *dynPUN* game and the *dynNOpun* game. Both games are dynamic games consisting of T rounds. In each round a public-good game is played. The games differ from a supergame with T repetitions of the stage games by two important aspects: (i) contribution capabilities depend on earlier play, and (ii) no roundly payoffs are paid. Instead, game payoffs are determined by the final-round wealth-levels only.⁵

In the *dynNOpun* game, each round $t, t = 1, \dots, T$, has exactly one stage in which a standard public-good game with n players is played. In the first

⁵This is an important difference to the study by Gächter et al. (2009), who implement (i) but not (ii). In their setup, roundly payoffs are paid as well as determining next-round endowments.

round, each player is endowed with an identical amount of E tokens. The contribution capability, or current wealth, of a subsequent round t , E_i^t , corresponds to player i 's last round's wealth Ω_i^{t-1} plus a 'recovery surplus' of m . In every round, each player i may contribute x_i^t tokens from her current wealth to a common project and keeps the remainder on a private account. The total contributions are multiplied by $n\mu$ and divided evenly amongst the players in the group, so that the public good exhibits a constant marginal per-capita return of μ . Thus, player i 's wealth Ω_i^t at the end of round t is:

$$\begin{aligned} \Omega_i^t &= E_i^t - x_i^t + \mu \Sigma_j x_j^t, \quad t = 1, \dots, T \\ \text{with } E_i^1 &= E. \end{aligned}$$

In the *dynPUN* game, a second stage is added. After the first stage, which is identical to that of the *dynNOpun* game, players are informed about all players' contribution decisions and may then assign punishment points to the other players in their group. By assigning p_{ij}^t points to player j , player i can reduce the round- t wealth of player j by p_{ij}^t . Punishment is not only costly for the punished, but also for the punisher. The assignment of p_{ij}^t points inflicts costs of $c(p_{ij}^t)$ on player i . The cost function is a convex function that is positive for all positive values of p_{ij}^t and monotonically increasing. We set two further constraints on punishment: players cannot assign values of p_{ij}^t that would drive their own current account below zero, and they cannot drive other players' current account at the end of the round below zero. If they assign more points than necessary to eliminate another player's positive earnings, they nevertheless have to bear the full costs of their choice.

The resulting function determining player i 's current *wealth* Ω_i^t at the end of round t is:

$$\begin{aligned} \Omega_i^t &= E_i^t - x_i^t + \mu \Sigma_j x_j^t - h(\Sigma_j p_{ji}^t) - \Sigma_j c(p_{ij}^t), \quad t = 1, \dots, T \\ \text{with } \Sigma_j c(p_{ij}^t) &\leq E_i^t - x_i^t + \mu \Sigma_j x_j^t \\ h(\Sigma_j p_{ji}^t) &= \min\{E_i^t - x_i^t + \mu \Sigma_j x_j^t, \Sigma_j p_{ji}^t\}, \\ \text{and } E_i^1 &= E. \end{aligned}$$

The next round's contribution capabilities are given by $E_i^t = \Omega_i^{t-1} + m$, where m is a small increment meant to reflect a player's natural regeneration capabilities and $\Omega_i^0 \equiv E, \forall i$.

2.1 “Standard” game-theoretic solution

The standard game-theoretic subgame-perfect Nash-equilibria of both games for rational selfish actors are obvious and equal to those of the corresponding ‘static’ supergames (i.e., for E_i^t that are independent of the contribution vector \mathbf{x}^{t-1} , and more often than not, invariant over time or even over players), following directly from the typical backward-induction argument. In other words, in the subgame-perfect equilibrium, no player will make positive contributions, nor punish other players in case of the *dynPUN* game. However, there is one notable difference between the games presented here and their respective ‘static’ counterparts: in our games, $x_i^t = 0, \forall i, t$, is no longer a dominant strategy. To illustrate the intuition behind this, consider a simple example of three players with an initial endowment of E and no between-round regeneration, such that the contribution capabilities in a given round $t', t' > 1$, equal the wealth level at the end of the preceding round ($\Omega^0 = E, m = 0, \mu = 0.5$, and $n = 3$). Consider player i and suppose that all other players j choose full contributions and no punishment, i.e., $x_j^t = E_j^t$ and $p_j = 0, \forall j \neq i$. No matter what the punishment technology is, a rational selfish player i will always set $p_i = 0$.⁶ A player i who always sets $x_i^t = 0$ would obtain $\Omega_i^T = E + T(2E/2) = (1 + T)E$. In contrast, if she chooses $x_i^t = E_i^t, t = 1, \dots, T - 1$, and $x_i^T = 0$, she obtains a payoff of $\Omega_i^T = 2(3/2)^{T-1}E$. It is easy to see that the second strategy will lead to higher payoffs for large enough T 's. In our simple example, two rounds are enough for the latter strategy to ‘break even’, while for $T = 3$, it already leads to a payoff of $4.5E$ instead of $4E$. Of course, this is not to suggest that the strategy presented would be the best-response to all other players

⁶We are abstracting from punishment technologies that convey a benefit to the punisher, rather than causing costs. In most societies, punishment technologies that do not follow this assumption are ruled out, probably in order to avoid misadministration of punishment driven by selfish motives to the largest possible extent.

contributing fully for all parameter combinations. In our exemplary case, a strategy starting to defect in the penultimate period would obtain the same payoff as the one defecting only in the final period. For the parameters used in our experiment, it would do even better. Note that, up to this point, we have neglected the possibility of positive punishment decisions, as well as of reactions to defecting behavior by the other players. The sole purpose of our example was to point out that the dynamics provide incentives to cooperation even for players maximizing only their own material payoff in case other players do not conform to the model assumptions of being rational and selfish. The reason for the non-dominance of free-riding is that it conveys players the power to increase others' later-round contribution capabilities through their own contributions in early rounds.

2.2 Solution with social preferences

How does the solution of the game change if one assumes that subjects have some kind of social preferences? For some guidance on what the answer to this question would look like, we discuss some arguments based on one of the most prominent and tractable social preference models, proposed by Fehr and Klaus M. Schmidt (1999). They show that in a standard linear public-good game, equilibria with positive contributions are possible if one assumes the existence of inequality-averse players. In these equilibria, a subset of “conditionally cooperative” players contribute a positive amount to the public good while the remaining players refrain from contributing. These equilibria exist as long as the contributors do not suffer too much from disadvantageous inequality. If punishment is possible on a second stage, there may be equilibria in which all players contribute positive amounts to the public good. These equilibria require a sufficient number of “conditionally cooperative enforcers” who highly dislike disadvantageous inequality. These “enforcers” are not only willing to contribute to the public good but also ready to credibly threaten purely money-maximizing players with punishment if the latter do not contribute.

What does inequality-aversion imply for our dynamic game? Rather than

conducting a comprehensive analysis of the dynamic game with socially concerned players, we provide an idea of the direction in which the existence of inequality-averse players changes the ‘standard’ predictions. Game payoffs correspond to the wealth levels at the end of the final period. For a one-shot four-player game with a marginal per-capita return as used in our treatments and without punishment opportunities, Fehr and Schmidt (1999) show that there is no equilibrium with positive contribution levels unless all players are “conditionally cooperative”. They go on to point out that, under inequality-aversion parameters as typically observed in economic experiments, the latter is very unlikely to happen.⁷ In our *dynNOpun* game, omni-lateral free-riding is the unique equilibrium in the final stage of the game if there is at least one money-maximizing player and the money-maximizing players’ final-period contribution capability is not lower than the conditional-cooperators’ one. In this case, a backward-induction argument leads to the conclusion that there cannot be positive contributions in any round. Hence, the standard equilibrium from the ‘static case’, in which no player ever contributes, also exists in our game. Furthermore, following from the same reasoning as in the one-shot game, there exists a second class of equilibria with completely symmetric contributions amongst a group of conditional cooperators who disregard potentially lower contribution levels by money-maximizing players. However, in our setting, this only applies for groups consisting only of conditional cooperators.⁸

Still, for the *dynNOpun* game, there is yet another class of equilibrium that may sound counter-intuitive at first sight. In these equilibria, money-maximizing players start out contributing their full endowment, while conditional cooperators abstain from contributing positive amounts in the first round. In following rounds, money-maximizers keep contributing their current wealth, while conditional cooperators mirror the formers’ action from the

⁷The parameter distribution suggested by Fehr and Schmidt (1999) results in that the chances for cooperation amount to 2.56% in a typical public-good game ($n = 4$, $\mu = 0.5$). The parameter distribution estimated by Mariana Blanco, Dirk Engelmann, and Hans-Theo Normann (2008) would lead to a similar conclusion.

⁸The condition for this class of equilibria to exist is obviously the same as spelt out by Fehr and Schmidt (1999) for the one-shot game.

respective preceding round. Only in the final periods do money-maximizing players free-ride completely, while conditional cooperators choose their contributions as to equalize payoffs with the money-maximizers.⁹

To understand the intuition behind this class of equilibria, consider again the final stage of the game. If conditional cooperators have higher final-period contribution-capabilities than money-maximizers, the former will contribute part of their current wealth to close the ‘wealth gap’, while the latter will obviously free-ride. In the preceding section we have pointed out that in *dynNOpun*, a payoff-maximizing player may have an incentive to contribute positive amounts to the public good even in the absence of any inequality concerns – given the assumption that other players will continue to contribute after the money-maximizer’s defection. In other words, it may be profitable for these players to make the pie bigger and free-ride only in the final rounds. By mirroring the money-maximizers’ contributions from the respective preceding round, conditional cooperators always choose the amount necessary to equalize wealth levels if all money-maximizers free-rode in the corresponding period. A thorough analysis of the proposed equilibrium is given in appendix B. Interestingly enough, these equilibria require conditions that are rather likely to be met, in stark contrast to those needed for cooperation in the one-shot game analyzed by Fehr and Schmidt (1999).¹⁰ In other words, unlike in the ‘static’ game the existence of inequality concerns could often lead to a high degree of cooperation.¹¹

⁹In fact, this class of equilibria is more general than proposed here. Money-maximizers’ equilibrium strategy could prescribe to contribute any arbitrary fraction of their wealth, as long as it is symmetric, and to stop contributing in period $T-t'$. The conditionally cooperative players would mirror money-maximizers’ contributions in the respective subsequent period and refrain from contributing positive amounts in all periods $t > T-t'+1$. However, the most efficient of these equilibria is the one with full money-maximizer contributions and $t' = 1$. Hence, this equilibrium would be chosen by the same equilibrium refinement argument Fehr and Schmidt (1999) employ to choose the full-contribution equilibrium.

¹⁰For the parameters used in our experiment, the likelihood of the preconditions for this equilibrium to be given amounts to roughly 35%, according to the type distribution suggested by Fehr and Schmidt (1999).

¹¹In the absence of common knowledge of other players’ types, this class of equilibria may vanish: selfish types could mimic the equilibrium strategy of the conditional cooperators, pretending to be one of them. However, if reciprocation in the final round is rather doubtful, incentives for contributions by other selfish types are diluted. However, theoretic analyses of games using Fehr-Schmidt-type preferences usually assume common knowledge

For a public-good game with punishment opportunities, Fehr and Schmidt (1999) show that equilibria exist in which all players contribute to the public good, given that at least some players have social preferences. In particular, they contend that “the ‘good’ equilibrium” stipulating full contributions by all players would be chosen by “a reasonable refinement argument”.¹² The prospects for such equilibria depend on the existence and the number of conditionally cooperative enforcers, the magnitude of their inequality preferences and the power of the punishment technology. In static public-good games with relatively small groups as used in most experimental studies ($n = 4$) and with a 1:3 punishment technology, the probability of a cooperative equilibrium is about eight times as high as in the game without punishment opportunities.¹³

Would we expect a similar effect for our treatments? The answer is no, for a number of reasons. First, as has been pointed out above, the prospects of a cooperative equilibrium in our *dynNOpun* game are not as low as in the corresponding ‘static’ game. Therefore, the increase in the probability of a cooperative outcome resulting from the introduction of a punishment mechanism will be far more moderate. Second, consider the final subgame. In case of very large wealth differences, an enforcer may no longer have an incentive or not be able to punish as much as would be required to equalize final payoffs due to our convex punishment technology. In fact, as can be easily shown, the optimal punishment choice of a player only depends on the total number of players, the number of enforcers, and her aversion to inequality, but not on the size of the inequality (unless this inequality is small, in which case a corner solution may result). Hence, the enforceable final-period contribution level is bounded from above. In contrast to the games most often played in the laboratory, this upper bound will tend to be

of types (most notably, Fehr and Schmidt, 1999, themselves). Rather than by its accuracy, this assumption has been justified by its predictive power. In light of this fact, we follow their example by making the assumption.

¹²Both p.842.

¹³For the preference distribution suggested by Fehr and Schmidt, the probability for cooperation in a static public-good game amounts to about 20% (with $n = 4$, $\mu = 0.4$, and a cost-to-punishment ratio of 1:3).

given by enforcer preferences rather than by players' wealth.¹⁴

On the other hand, for the class of positive-contribution equilibria in the *dynNOPun* game described above, the 'equivalent' for the *dynPUN* game will display higher contribution levels, for two reasons: (i) payoff-maximizers can be forced to contribute a certain level even in the final period, and (ii) the threat of (partial) non-reciprocation in the final period leading payoff-maximizers to contribute earlier on can partially be substituted for by the threat of sanction assignment. Thereby, the conditional cooperators are able to increase their own contributions in earlier periods beyond what is necessary to equalize payoffs for the case of defecting money-maximizers, in turn increasing the overall final wealth level.

In summary, in the presence of social preferences the introduction of punishment opportunities enhances both the prospects of a cooperative outcome and the size of contributions in the 'static' public-good games commonly used in the literature. In contrast, in our dynamic version of the game, the social-preference model proposed by Fehr and Schmidt (1999) would predict a substantial difference only in the achieved contribution levels, while the predicted difference in the probability of an outcome with non-negligible cooperation rates tends to be rather small.

2.3 Research hypotheses

We have seen in the preceding game-theoretic analysis that in the presence of players motivated by social considerations, a dynamic public-good game with endogenously evolving contribution capabilities provides incentives for

¹⁴For the parameters used in our game in conjunction with the parameters suggested by Fehr and Schmidt (1999), the largest possible optimal number of assigned points is 15.4 per punishing player for 3 enforcers, and 5.8 points per enforcing player for two such players. If there is a single enforcer, there will not be any point assignment, as the marginal costs of punishment (equal to $1/3$ at 0 punishment points) are higher than the 'enforcer's' marginal benefit from punishment. Note, for comparison, that the average final-round contribution-capability level amounts to over 2000 tokens. For the derivation of the optimal choice of punishment points, the interested reader is referred to the calculations of Fehr and Schmidt (1999), as a reproduction of their calculations would not provide any new insights. The only difference between their case and ours is that the costs are no longer linear, and thus, we do not (necessarily) obtain a corner solution.

cooperation. In the ‘static’ case, punishment leads to an increase in both the level of contributions and the prospects of a cooperative outcome, while in our game, only the former is expected. However, these are equilibrium considerations that rely on a considerable number of assumptions. Notably, they presume that there will not be any punishment actions, as the punishment threat is credible and sufficient to deter deviations from the prescribed contribution levels. From the vast amount of experimental evidence on public-good games with punishment we know that these conditions are fulfilled hardly ever.¹⁵ While the threat of sanctions is generally “credible” in the sense that subjects do assign punishment points, it is often not “credible and sufficient” enough to induce high contributions early on in the experiment. At the same time, the efficiency costs of punishment are often so high that the average period payoff is reduced below the no-contribution equilibrium level in early rounds. In a game in which contribution capabilities do not depend on earlier play, this characteristic often does not have an enduring effect, as stable or growing contribution levels insure that final – and often total – earnings surpass those from the comparable game without sanctions.¹⁶ In a game with endogenously evolving contribution capabilities, however, a “conditionally cooperative enforcer” has to strike a balance in the following trade-off: punishing a low-contributing player may induce higher future cooperation levels, but at the same time, it destroys parts of the future contribution capabilities of both the punisher and the punished player. This tension provides the base for two extreme benchmark scenarios that we will use as our research hypotheses.

The first scenario pictures that a group falls prey to a ‘poverty-trap’ due to excessive punishment. Punishers put too much weight on the cooperation-enhancing effect of punishment, neglecting its costs. Heavy punishment in early rounds - as often reported in static settings - will not only decrease

¹⁵For an overview, cf., e.g., Gächter and Herrmann (2009).

¹⁶Cf., e.g., Nikiforakis and Normann (2008). A notable exception is to be found in the study by Gächter, Elke Renner, and Sefton (2008) for the groups playing over 10 rounds; in their case, average earnings in the punishment treatment never reach those from the punishment-free institution, and in all but two rounds, average earnings are below the benchmark set by omnilateral defection.

round-wise efficiency but will have serious repercussions on subsequent contribution capabilities and thus, achievable wealth levels in subsequent rounds. In other words, even if punishment leads to higher contributed fractions of current wealth (as it usually does), if it keeps wealth levels down, contributions will still be lower. Furthermore, even in the case of growing wealth levels, punishment will not necessarily lead to higher contributions in the long run; if the initial disadvantage is large enough, catching up with non-punishing societies may take a very long time – potentially longer than our experimental sessions.¹⁷ At the same time, catching up may be difficult for another reason: enforcers will need to uphold the punishment threat, unless groups entirely consist of conditional cooperators. With rising wealth and envisioned relative contributions that are at least stable, assigned points will need to be higher to do their job. Simultaneously, our convex punishment technology makes higher penalties disproportionately more expensive. However, relatively inefficient punishment will not be able to uphold contributions the same way more efficient cost-to-effect ratios do, which may in turn induce contributions to fall again even in the presence of an initially successful punishment mechanism (see e.g., the results of Nikiforakis and Normann, 2008, on different cost-to-effect ratios).

H 1. *Groups in dynPUN fall prey to a poverty trap, i.e., punishment actions diminish future contribution capabilities such that contributions remain below those in the dynNOpun treatment, while relative contributions (measured against players' current wealth) may or may not be higher. Consequently, payoffs will be lower in the treatment with punishment opportunities.*

If, on the other hand, players foresee the detrimental effects harsh punishment in early periods may have, they may refrain from contribution enforcement, which may render the punishing mechanism ineffective. Alternatively,

¹⁷Cf. Gächter et al. (2008); given we only have subjects play over 20 rounds, their different results for large numbers of repetitions may not apply. At the same time, the number of rounds used in the present study is substantially higher than in other studies for which a beneficial effect of punishment has been documented, such as most treatments in Nikiforakis and Normann (2008; note that their 1:2 punishment technology only leads to a non-significant increase in cumulative earnings).

punishment may not even be needed, given the increased incentives for cooperation provided by a combination of social preferences and dynamic incentives. In this case, punishment opportunities would not lead to a cooperation-enhancing effect, either, but this time as a consequence of groups without punishment performing too well. Taking together the expected effects of dynamics fostering aggregate payoffs in a non-punishing world and of impeding the positive effects of punishment in a world where the latter is an option, we propose the following competing hypothesis on contribution and punishment behavior:

H 2. *Players in dynPUN abstain from contribution enforcement in order to save the group’s resources. In consequence, the cooperation-enhancing effect of punishment vanishes. Therefore, contributions in absolute and relative terms are non-distinguishable between the treatments, as are payoffs.*

An important feature of our study is that the game structure inherently leads to asymmetric wealth levels, unless all players cooperate to exactly the same degree. A widely-received feature of public-good studies with heterogeneous endowments is that “rich participants typically contribute less in relative terms than poor participants do.”¹⁸ For our study, we expect this to hold in heterogeneous but not in homogeneous groups: in case there are (partial) free-riders as well as full-contributors, the assertion will hold true automatically, and if players have the often-assumed types – pure cooperators, defectors, and punishers – it will also be a self-fulfilling prophecy. In contrast, in groups exclusively composed of either free-riders or full-contributors, we will not be able to make a statement of that kind. A comparison across groups, on the other hand, will most likely yield mixed results, given the “rich” will be a mixture of free-riders from mixed groups and full-contributors in more homogeneous groups. In other words, we expect to be forced to qualify the above assertion as a consequence of the endogeneity of subjects’ (relative) wealth levels.¹⁹ This is an important difference to the setting of Sadrieh

¹⁸M. Vittoria Levati, Matthias Sutter, and Eline van der Heijden (2007, p. 812). For a study on heterogeneous punishment technologies, see Nikiforakis, Normann, and Brian Wallace (forthcoming).

¹⁹Todd L. Cherry, Stephan Kroll, and Jason F. Shogren (2005) examine a different kind

and Verbon (2006) who induce wealth heterogeneity exogenously. While they find that “[a]pparently, the poor do not blame the rich for their own poverty,” this cannot be expected in our game.²⁰ In our setting, “the poor” cannot but blame “the rich” for their low level of wealth, as the latter are richer than the former because of the previous decisions taken.

A second finding from a number of studies of a linear public-good technology employing heterogeneous wealth or endowment levels is that average contributions are lower than under homogeneous ones (see e.g., Lisa R. Anderson, Jennifer M. Mellor, and Jeffrey Milyo, 2007; Cherry, Kroll, and Shogren, 2005, or the literature surveyed in Kenneth S. Chan et al., 1999).²¹ For our study, we do not expect clear evidence in this regard because of the reasons outlined above: homogeneity will be high both in very wealthy and very poor “societies”, while it will take on intermediate values in those groups in between.

3 Experimental design and procedure

In our experiment, we implemented the games described in section II, with the following parameter values: $n = 4$ subjects interacted within a fixed group over $T = 20$ rounds. The initial endowment was defined by $\Omega^0 = 18$, and $m = 2$, such that $E_i^1 = 20, \forall i$. The public good’s marginal per-capita return was set to $\mu = 0.4$, and punishment costs were calculated according to the following formula:

$$c(p_{ij}) = \frac{1}{3}p_{ij} + \frac{p_{ij}^3}{2000}. \quad (1)$$

This formula was chosen such as to preserve the standard cost-to-punishment ratio of 1:3 for low values of punishment points, but to reflect the increas-

of endogenous wealth asymmetry, having subjects earn their endowments for a one-shot public-good game to test whether the origin of endowments leads to differences in behavior.

²⁰Sadrieh and Verbon (2006, p. 1219).

²¹For other public-good technologies, different results obtain, as in the case of Sadrieh and Verbon (2006). For a more detailed review, cf. Chan et al. (1999), or Levati et al. (2007).

ing difficulties real-life punishers would be expected to be faced with when setting out to destroy larger amounts of wealth. After observing others' contributions, subjects in the *dynPUN* treatment were asked to indicate the players they wanted to assign points to or to indicate that they did not want to assign points to any other player before being allowed to punish those players indicated. This was done for two reasons: (i) to avoid a punishment-related experimenter-demand effect as much as possible, and (ii) to ensure consistency with our econometric procedure of separating the decisions on whether to punish and on how many points to assign.

Our experiment was programmed in z-Tree (Fischbacher, 2007) and run at the Laboratory for Experimental Economics (eLab) at University of Erfurt. We ran 4 sessions, 2 for each of our treatments. A total of 72 subjects were recruited using ORSEE (Ben Greiner, 2004). In each session, subjects were welcomed and asked to draw lots, in order to assign each of them to a cabin. Once all subjects were seated, the instructions were handed to them in written form before being read aloud by the experimenter. After this, subjects were given the opportunity to go over the instructions again and ask any questions they might have. Questions were answered individually.

At the beginning of the experiment, each subject was assigned an identification letter (R, S, T, or U) that was kept constant over the course of the experiment. Assignment to groups was random and groups did not change during the entire session. In each session, there were either 4 or 5 matching groups, so that we obtained 9 independent observations for each treatment.

Subjects were paid according to their individual performance according to the following formula:

$$\text{Payment in Euros} = (\text{Number of experimental tokens accumulated})^{2/7}$$

This translated into possible payments between 0 and 40 Euros. The sessions lasted approximately three quarters of an hour, average payments being 8.30 Euros. Payments were settled individually to ensure players' anonymity. Also, no other information was given to the subjects that would enable them to connect the players in the game with the respective subjects in the session.

4 Results

As a first indicator for the performance in the two treatments, we focus on the average wealth levels. Figure 1a shows that they increase monotonically in both treatments. While wealth levels are (weakly) significantly lower in *dynPUN* in the first (second) quarter of the experiment, they are not statistically different afterwards (p -values by quarters are 0.0142, 0.0939, 0.2581, and 0.7304).²²

Result 1. *In an environment where contribution capabilities are determined by past contribution levels, groups under a peer-punishment mechanism suffer an initial disadvantage in terms of their wealth level, compared to groups in a treatment without punishment opportunities. This difference is made up for by the second half of the experiment.*

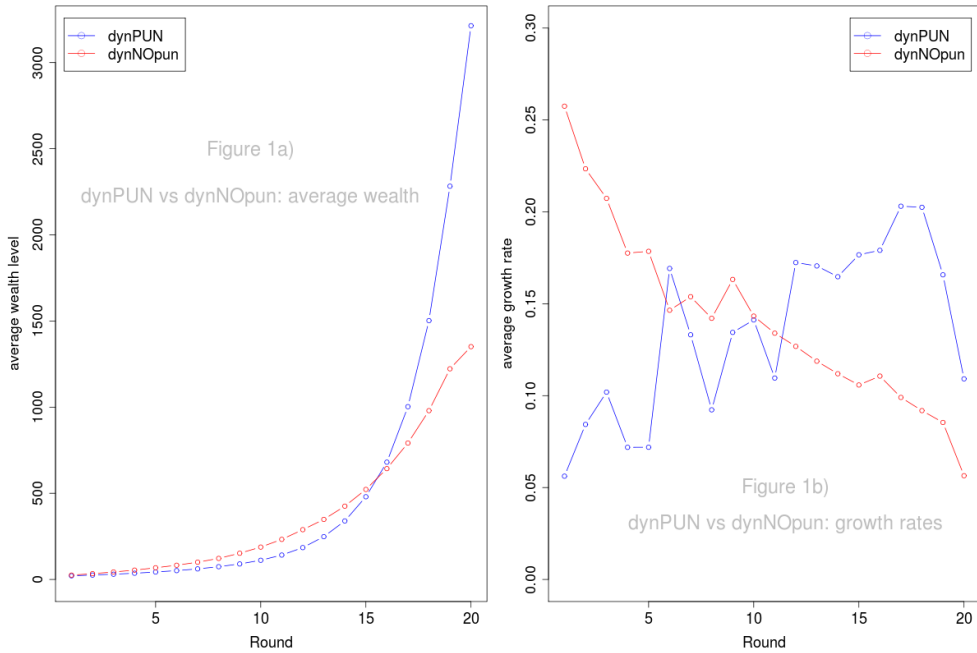


Figure 1: a) Average wealth levels from both treatments (left), and b) and average growth rates of wealth (right).

²²Treatment comparisons are always made by means of two-sided Mann-Whitney U tests.

In other words, groups in the *dynPUN* treatment manage to overcome an initial disadvantage, but they do not surpass the groups from the *dynNOPun* treatment. In relation to the potentially achievable wealth level, our subjects only obtain 1.14% (0.48%) in *dynPUN* (*dynNOPun*). Figure 1b, displaying average wealth-level growth rates, illustrates the history leading to these low percentages. Out of the theoretically possible benchmark of 60% growth, average growth rates do not reach even half. Having said that, we notice two very distinct growth paths in our treatments. While the average growth rate is significantly higher in *dynNOPun* in the first quarter ($p = 0.0315$), it declines almost monotonically from 26% to 6%. The growth rate in the *dynPUN* treatment keeps rising from a mere 5% to just over 20% in round 18, before the end-game effect kicks in for the final two rounds. However, the difference in growth rates in favor of the *dynPUN* treatment after period 11 does not reach statistical significance before the end of the experiment.²³

To obtain a better understanding of how these (non-)differences in wealth levels and growth rates come about, let us turn to subjects' contribution decisions. Surprisingly, and contrary to the findings from previous research on peer-punishment in public-good games, we do not find significant treatment differences in terms of contributions in any of the 20 rounds.²⁴

Result 2. *In an environment where contribution capabilities are determined by past contribution levels, a peer-punishment mechanism does not increase contribution levels beyond those in a punishment-free environment.*

However, if we look at what subjects contribute as a part of their current capability, which we will refer to as relative contribution, we observe the well-known pattern of initially similar but diverging contribution paths. We illustrate this pattern in Figure 2. In *dynNOPun*, average relative contributions start out at 43%, falling over time in what is almost a monotonic fashion to 17% in round 18, while they slightly increase from 37% to 41% during the same time period in *dynPUN*.²⁵ The treatment difference in relative

²³ p -values for quarters 2-4 are $p_{6-10} = 0.9314$, $p_{11-15} = 0.5457$, and $p_{16-18} = 0.2973$ ($p_{16-20} = 0.3401$).

²⁴Apart from the final round ($p = 0.1217$), p -values are always above 0.25.

²⁵A spearman correlation test between the average relative contribution and time over

contributions is not significant but for the final quarter ($p_{16-20} = 0.0503$), even though the *dynPUN* average already surpasses the one in *dynPUN* as early as in the third period.

Result 3. *Contributed fractions of current wealth do not fall over time in the presence of a peer-punishment mechanism, while they exhibit the typical declining trend in its absence. The difference in relative contributions is significant at the end of the experiment.*

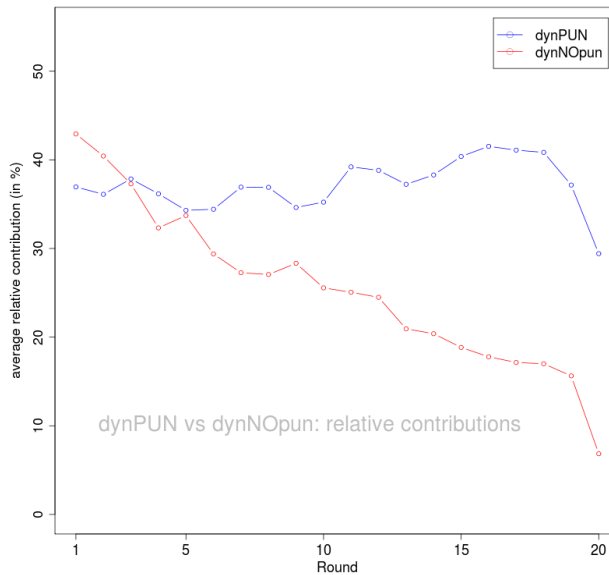


Figure 2: Treatment averages over contribution levels relative to current capabilities.

Still, the question remains of why this advantage does not translate into higher contributions within the time frame set by our design. Naturally, the answer has to be in the resources destroyed by punishment.

In Figure 3a, we depict the average fraction of public-good surplus destroyed by punishment actions (i.e., the sum of the punishers' costs and punished players' losses). As can be seen from the figure, more than half of a group's surplus is eaten up by punishment actions especially in the first half of the experiment. Overall, an average of 62% of the groups' growth the whole experiment has a p -value of 0.0612.

is lost. The fact that this problem is even more pronounced in the beginning of the experiment can account for the humble performance of the average *dynPUN* group and its difficulty to outperform the average group in the *dynNOPun* treatment: as stated before, it leads to a significantly worse early-round performance of groups in *dynPUN*. This creates a disadvantage that is aggravated by the power-function character of our payoff function as ‘production capacities’ are determined by past performance.

Result 4. *On average, the use of punishment destroys 62% of a group’s gains from cooperation, thereby explaining the uncommonly low level of contributions when compared to the punishment-free environment.*

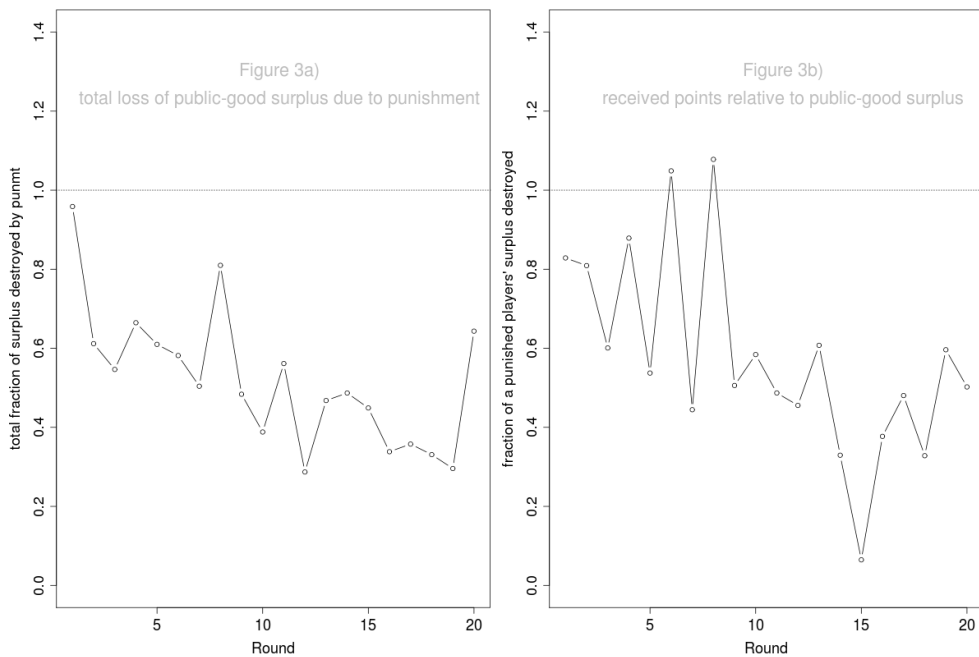


Figure 3: a) Average fraction of public-good surplus destroyed by punishment actions; b) Average fraction of punished players’ surplus destroyed, (i.e., conditional on the players being punished).

Another question concerns the impact such punishment has on the individual player, most importantly, how strongly received punishment affects a punished player’s wealth. We depict this in Figure 3b, showing that on

Table 1: Punishment statistics from the four punishment treatments from Nikiforakis and Normann (2008), and from our *dynPUN* treatment. The ratio of 1:2.8 given for our treatment refers to the average effective ratio in our experiment.

Technology	Nikiforakis and Normann (2008)				Our data *1 : 2.8*
	1:1	1:2	1:3	1:4	
Fraction of wealth destroyed	0.0935	0.1141	0.1154	0.0653	0.0919
PunRcvd/(wealth after the public-good stage)	0.0391	0.0714	0.0807	0.0482	0.0636
...cond. on receiving punishment	0.1204	0.1880	0.2257	0.3271	0.1304
Number of punishment assignments	0.4500	0.5208	0.4458	0.2708	0.7194
...cond. on this number being positive	1.3118	1.5122	1.4850	1.2490	1.4362
punExp/(wealth after the public-good stage)	0.0543	0.0427	0.0346	0.0171	0.0254
...cond. on punmt expenses being positive	0.1444	0.1216	0.0982	0.0677	0.0474

average, punished players are left with more than their wealth at the beginning of the round. Only in two rounds out of twenty do these players lose (slightly) more due to reduction points than what they have gained from the public good before the punishment stage. What does not happen, on average, is that punished players' wealth is brought to shrink. One reading of this finding is that punishers take care not to waste too many resources for future group production. To obtain a clearer picture of whether punishment is meted out in a more cautionary way than usual, we compare our data to data from a 'static' experiment comparing different linear punishment technologies that was conducted by Nikiforakis and Normann (2008). Knowing that the figures calculated from these two different data sets can at best give us an indication of the main trends, we compare them in table 1.

From Table 1 we see most indicators are rather similar between the two

experiments, despite the differences in the experimental setup. A notable difference is that punishment expenses and points received conditional on punishment meted out/received tend to be on the lower end of the distribution in our experiment, but more strikingly, that the number of punishment actions is substantially higher. In light of the fact that this number is not different when conditioned on punishment being effected, in our experiment, more players seem to take a share in sanctioning misbehavior. In other words, while those who punish tend to assign less points than under the linear technologies employed in Nikiforakis and Normann (2008), more players are engaged, leading to a similar impact on punished players' wealth levels.

Result 5. *Compared to data from 'static' environments with comparable cost-to-sanction ratios, subjects in our punishment environment seem to punish more often but more moderately.*

To understand how such frequent but moderate punishment impacts on contribution behavior, we conduct a number of Wilcoxon tests. The most striking result is that the likelihood of an increase in (relative) contributions after a player experiences sanctions is not significantly different from the case when the player is not punished ($p = 0.2031$ for contributions, $p = 0.1641$ for relative contributions).²⁶ Furthermore, the size of the change in contributions from one period to the next conditional on being punished is not significantly higher, either ($p = 0.1386$). Only the size of relative contribution changes is significantly larger after experienced punishment ($p = 0.0152$).²⁷

²⁶The result for relative contributions is particularly intriguing for the following reason: given sanctions are directed predominantly from high- to low-contributors, we would expect an increased fraction of positive reactions after punishment even for a player choosing her contributions randomly from any symmetric distribution over the range of possible contribution choices. Only players who always contribute a constant fraction of their wealth (which we do not observe) or players responding negatively to received punishment would not increase their relative contributions. On the other hand, players not being punished tend to be those with higher contributions. An increase in their relative contribution level would be expected to be less likely.

²⁷This, however, can be due to two different reasons: (i) subjects may think in terms of relative contributions, thus increasing their relative contributions after being subject to sanctions. (ii) They focus on the absolute contribution level (as well), with a tendency to keep it constant; in this case, punishment need not influence contribution behavior but leads to an increase in relative contributions merely by reducing contribution capabilities.

To further explore this positive effect of punishment on relative contributions and find out how other factors pertaining to social comparisons influence contribution decisions, we conduct the regression analysis reported in Table 2.²⁸ We contrast the results from this regression analysis to those from a similar analysis conducted on the data from our *dynNOPun* treatment in order to find out how the introduction of a punishment mechanism changes the data-generating process.

In the first model reported in table 2, we regress a player’s period-to-period change in relative contributions on a number of lagged variables, namely the deviation of her relative contribution from the other group members’ average contribution to test whether players condition their behavior on others’ decisions; her contribution capability’s deviation from the others’ average capability to account for players’ “historical” relative wealth levels within their society; and the deviation of the player’s surplus from the public good from the others’ average surplus; furthermore, a dummy variable indicating whether the player had been sanctioned in the preceding round, as well as the fraction of the player’s current (i.e., interim) wealth destroyed by others’ assignments. All mentioned deviations are normalized using the average (except for the comparisons of relative contributions), and split into two positive variables to allow for differential effects of above- and below-average values. Finally, we include the variation coefficient of players’ current contribution capabilities to control for heterogeneity within the group, the logarithm of the average capability to account for the current group level of prosperity, and the period to allow for potential time trends. In the second model, we use the same framework on the data from our *dynNOPun* treatment, naturally excluding all variables pertaining to punishment.

A finding that is common to both data sets is that negative deviations from the average surplus from the public good lead to significantly lower contributions in the following round. What this means is that high-contributors show particularly negative reactions to wealthy free-riders, that is, to free-riders with a history of defecting. At the same time, having a history of

²⁸Only data from periods 1 to 19 is included, to keep our data as clean as possible from endgame effects. Significance levels are indicated as follows: ***0.001, ** 0.01, * 0.05.

Table 2: Results from a linear GLS regression of period-to-period changes in relative contributions, with individual random-effects and errors clustered by groups.²⁸

Variable	<i>dynPUN</i>	<i>dynNOpun</i>
Positive deviation from the average relative contribution in $t - 1$	-0.1731 (0.1104)	-0.1809* (0.0846)
Negative deviation from the average relative contribution in $t - 1$	-0.0037 (0.0765)	0.2157 (0.1497)
Positive deviation from the average capability in $t - 1$, normalized [‡]	-0.0172 (0.0151)	-0.0182 (0.0279)
Negative deviation from the average capability in $t - 1$, normalized [‡]	0.0807 (0.0747)	0.1835*** (0.0452)
Positive deviation from the average surplus from the public good in $t - 1$, normalized [‡]	0.0087 (0.0075)	0.0036 (0.0068)
Negative deviation from the average surplus from the public good in $t - 1$, normalized [‡]	-0.0604*** (0.0162)	-0.0699* (0.0313)
Dummy: having been punished in $t - 1$	0.0011 (0.0131)	
Received punishment as a fraction of the current wealth level in $t - 1$	0.2009** (0.0612)	
Variation coefficient of the group's current contribution capabilities	-0.0023 (0.0221)	-0.0862*** (0.0228)
Period	-0.0013 (0.0011)	0.0021 (0.0019)
Logarithm of the group's average contribution capability	0.0094* (0.0039)	-0.0056 (0.0071)
Constant	-0.0206 (0.0171)	0.0071 (0.0240)

[‡] Deviations are normalized by division by the average contribution capability and average surplus, respectively.

being a high-contributor in *dynNOpun*, – as evidenced by a comparatively low lagged contribution capability – tends to lead to higher contributed fractions of wealth, similar to the results of Sadrieh and Verbon (2006). However, this effect is being compensated by another effect found in this treatment,

namely that having contributed a higher fraction of one’s wealth than the other group members in the preceding period leads to a significant reduction of relative contributions. In other words, in this treatment players are eager to adjust contribution levels downwards when they learn that their relative contribution had been comparatively high – unless they are unconditional high-contributors, in which case relative contributions will tend to remain constant. With punishment being possible in *dynPUN*, contribution capabilities do not perform as an indicator for past contribution behavior in the same way as they do in *dynNOpun*. This may be a possible reason for why we do not see comparable effects in the regression on our *dynPUN* data, as not being able to separate between high-contributor types and sporadic high-contributors will drive up the variance of observed behavior (as can be seen from the higher standard errors of the respective *dynPUN* coefficients, compared to those from the *dynNOpun* treatment). In terms of the level of prosperity within our small societies as measured by the logarithm of the group’s average current contribution capability, we find a significant contribution-fostering effect only in *dynPUN*. This effect seems to be owed to the fact that in the better-performing groups in this treatment, players’ relative contribution levels exhibit a converging tendency. Given this convergence is towards higher contribution levels, and in light of the fact that it happens while the corresponding groups accumulate growing prosperity levels, growing capabilities will be associated with positive contribution changes. In light of this fact, the significance of the reported effect is not surprising. On the other hand, taking a look at individual group data we see that in the non-punishment groups, the attempts to induce a high level of group cooperation on the part of unconditional high-contributors by setting a good example are successful only to the degree that relative contribution levels in the respective groups tend to remain constant rather than decline as they do in other groups.²⁹ At the same time, long-term contributors tend to lower their contributions towards the end of the experiment, having seen their hopes of reciprocation dashed.

²⁹For an overview of the data, cf. the panel figures C.1 and C.2 included in appendix C.

In contrast, an increase in the gap between poor and rich leads to less cooperative behavior only in the treatment without punishment opportunities. An additional regression reported in appendix C that incorporates an interaction term between the period and heterogeneity of contribution capabilities suggests an explanation for the non-effect in *dynPUN*. In the beginning, a higher level of endogeneity has a significant positive influence on contributions, as it means that there is a fraction of players willing to keep investing in the public good even though others have not met the same cooperation standards straight away. In these groups, as was pointed out before, players with lower cooperation levels tend to increase their contributions. In essence, this means that in general, players tend to increase their contributions in groups with high initial degrees of heterogeneity. Over time, however, this trend is reverted: in the second half, heterogeneity leads to a decrease in the contribution level. This seems to suggest that groups have separated themselves: in some groups, contribution levels have converged, leading to a low degree of heterogeneity, in others, early-investors' patience is exhausted. In summary, the presence of the punishment mechanism seems to prolong the early-investors' patience, as the interaction term's coefficient is not significant in the corresponding analysis on the *dynNOPun* data and the term for wealth heterogeneity remains clearly below zero.³⁰ This reading would suggest that the punishment opportunities provide an avenue to vent one's anger as has been documented, e.g., by Dominique J.-F. de Quervain et al. (2004). At the same time, the detrimental effect of heterogeneity in *dynNOPun* is in line with the results of earlier studies of endowment heterogeneity such as Anderson et. al (2007) or Cherry et al. (2005).

Finally, in terms of punishment our regression analysis (cf. Table 2) is able to give a more complete picture than the Wilcoxon tests reported above. While the analysis confirms that the dichotomous variable of 'having been punished' does not have an effect on relative contributions, we are able to say more about the effect of different degrees of severity of punishment.³¹ By

³⁰More precisely, the term almost doubles, at the same time becoming insignificant; the remaining coefficients of this regression analysis are similar in size and significance level to those for the reported regressions, not conveying any new meaningful information.

³¹In an unreported regression, we substitute three dummies corresponding to the poten-

controlling for players' contribution capability, we see that punishment does more than simply to increase relative contributions through its capability-decreasing nature. Furthermore, the size of the effect suggests that, for strong free-riders in otherwise high-contributing groups, punishment may lead to an increase in contributions even in absolute terms.

5 Discussion and Implications

In our paper, we set out to extend the existing body of research on behavior in social-dilemma situations in an important direction. In a public-good game we introduce dynamics by letting a player's contribution capabilities depend on that player's and her group's past behavior. This was done to reflect a feature of many everyday dilemmas, namely that tomorrow's contribution capabilities may depend on today's decisions. In this environment, we examine the effects of a punishment technology to explore whether punishment has the same contribution-enhancing effect as in the static setting even though the preconditions seem to be worse.

Our dynamics give rise to three critical issues: (i) punishment in early rounds may have a lasting detrimental effect on contribution capabilities (**H1**), (ii) potential punishers anticipating this may abstain from sanctioning, making the punishment institution pointless (**H2**), and (iii) with growing wealth levels and a convex punishment technology, the institution may lose its contribution-enforcing power over time, leading to stagnating contributions in later periods (**H1**). Summarizing our results, we find that punishment, being particularly strong in early rounds does have a detrimental effect on contribution capabilities (**Result 4**), as subjects do not abstain from sanctioning. To the contrary, compared to a study of peer-punishment mechanisms comprising similar cost-to-sanction rates as the punishment technology employed in our experiment, the average number of punishers is sur-

tial numbers of other group members assigning punishment points to the respective player for the dichotomous variable of "having been punished". The results do not differ from those reported above, in particular, none of the coefficients corresponding to the number of punishers turns out to be significantly different from zero.

prisingly high (**Result 5**). On the other hand, the average number of points assigned per punishment action is relatively low. In light of the convexity of our punishment cost function, splitting the burden of sanctioning costs is a very sensible thing to do, as it saves resources on the punishers' side without changing the threat potential with respect to free-riders. At the same time, the loss in contribution capabilities is offset by the punishment mechanism's ability to keep the contributed fraction of players' current wealth levels constant (**Result 3**). As a result, we do not find any difference in the contribution levels across treatments during the course of our experiment (**Result 2**). Corresponding to the combined effect of a divergence in relative contribution levels and the diminishing trend of surplus destroyed due to punishment in the *dynPUN* groups, we observe increasing growth rates in the punishment environment, contrasting with falling rates in *dynNOpun*. At the end of our experiment, wealth levels in *dynPUN* have caught up with those in the treatment without punishment opportunities. In fact, they are already higher, even though this difference is not large enough to yield a statistically significant difference (**Result 1**). Nonetheless, with non-distinguishable wealth levels, substantially higher relative contributions and decreasing fractions of public-good surplus destroyed through punishment, it seems merely a question of time when the difference in contributions and, subsequently, wealth levels is strong enough to be statistically discernible.

Having seen the effects of a punishment mechanism on the aggregate level, we set out to find out more about the mechanisms at work on the individual level, apart from the straightforward effect of lowering individuals' contribution capabilities. In terms of direct effects, a regression analysis reveals that punished players' reactions are independent of the number of sanctioning players, only depending on their total size. Furthermore, it shows that the increase in relative contributions is more than just a consequence of reduced capabilities coupled with a fixed level of contributions. In other words, punishment does have a contribution-enhancing effect that goes beyond pure embellishment.

Looking at the punishers themselves, the assignment of sanctions seems to have a second positive effect. It seems to prolong high-contributors' pa-

tience with their peers, giving them more time to reciprocate. While in the *dynNOPun* treatment, such patience seems to be limited to a rather small number of unconditional high-contributors, players with a punishment possibility are not as eager to correct their cooperation levels downwards when learning that their contribution level was above the group average. Being given the chance to sanction low-contributors, they have another way to display their anger than to reduce their contributions straight away. This leads to the reported higher relative contributions and finds its expression in the fact that a higher variance in wealth levels does not automatically lead to lower contribution levels, thereby qualifying the earlier results of studies like Anderson et al. (2007) or Cherry et al. (2005).

We have embarked on this inquiry into the effects of a punishment mechanism in a dynamic public-good game in which players' contribution capabilities are endogenously determined by their behavior in preceding rounds by spanning a range of possible outcomes. On the one extreme, our benchmark scenario **H1** postulated the level of punishment would be so high that endowments could shrink over time and contributions would be lower than in the treatment without punishment in spite of significantly higher relative contribution levels. On the other, scenario **H2** postulated we would not observe punishment, as potential punishers would be too concerned about maintaining future contribution capabilities.

Our main results lie in between, suggesting a beneficial effect of punishment if the time horizon is long enough. Does this mean our scenarios were completely unjustified? The answer is no. While we do not observe any group in which wealth levels actually decrease – abstracting from the occasional period – there was one group in *dynPUN* in which all individual relative contributions are well above the median (and average) relative contribution from the *dynNOPun* treatment for most of the time – and yet, this group's wealth levels stay as low as in the second-worst performing *dynNOPun* group. On the other extreme, we have a group in which punishment was virtually never used before the kicking in of the end-game effect in round 19.³² This

³²As a matter of fact, there was a single assignment of 1 punishment point in period 16. In the final two periods, there were 2 (4) assignments, destroying 34 (50) out of 1216

group's performance corresponds to the median group from the treatment without punishment opportunities.

Summing up, we observe that punishment enhances cooperation even in a dynamic setting, and even for a convex technology that makes the destruction of a given wealth fraction more and more costly, the more wealth levels grow over the course of our experiment. In this sense, our results are a reassuring sign of robustness for public-good studies on punishment. At the same time, they underline the fact that peer-punishment will not be a suitable solution of social dilemmas for all groups: in a dynamic setting, its double-edged character clearly asserts itself: in some instances, the enhancement of cooperation comes at too high a price, leading the respective society to end up worse than it might have in the absence of sanctioning opportunities.

References

- [1] **Admati, Anat R., and Motty Perry.** 1991. "Joint projects without commitment." *Review of Economic Studies*, 58(194):259–276.
- [2] **Anderson, Lisa R., Jennifer M. Mellor, and Jeffrey Milyo.** 2008. "Inequality and public good provision: An experimental analysis." *Journal of Socio-Economics*, 37(3):1010–1028.
- [3] **Blanco, Mariana, Dirk Engelmann, and Hans-Theo Normann.** 2008. "A Within-Subject Analysis of Other-Regarding Preferences." Working Paper. Royal Holloway, University of London.
- [4] **Buckley, Edward, and Rachel Croson.** 2006. "Income and wealth heterogeneity in the voluntary provision of linear public goods." *Journal of Public Economics*, 90(4–5):935–955.
- [5] **Chan, Kenneth S., Stuart Mestelman, Rob Moir, and R. Andrew Muller.** 1999. "Heterogeneity and the voluntary provision of public goods." *Experimental Economics*, 2(1):5–30.

(1259) points in period 19 (20; punisher costs included).

- [6] **Cherry, Todd L., Stephan Kroll, and Jason F. Shogren.** 2005. "The impact of endowment heterogeneity and origin on public good contributions: evidence from the lab." *Journal of Economic Behavior & Organization*, 57:357–365.
- [7] **Dawes, Robyn M.** 1980. "Social dilemmas." *Annual Review of Psychology*, 31:169–193.
- [8] **Denant-Boemont, Laurent, David Masclet, and Charles Noussair.** 2007. "Punishment, counterpunishment and sanction enforcement in a social dilemma experiment." *Economic theory* 33, 145–167.
- [9] **Dharmapala, Dhammika, and Nuno Garoupa.** 2004. "Penalty Enhancement for Hate Crimes: An Economic Analysis." *American Law and Economics Review*, 6(1):185–207.
- [10] **Fehr, Ernst, and Urs Fischbacher.** 2003. "The nature of human altruism." *Nature*, 425:785–791.
- [11] **Fehr, Ernst, and Simon Gächter.** 2000. "Cooperation and punishment in public goods experiments." *American Economic Review*, 90(4):980–994.
- [12] **Fehr, Ernst, and Simon Gächter.** 2002. "Altruistic punishment in humans." *Nature*, 415:137–150.
- [13] **Fehr, Ernst, and Klaus M. Schmidt.** 1999. "A theory of fairness, competition, and cooperation." *Quarterly Journal of Economics*, 114(3): 817–868.
- [14] **Fershtman, Chaim, and Shmuel Nitzan.** 1991. "Dynamic voluntary provision of public goods." *European Economic Review*, 35(5):1057 – 1067.
- [15] **Fischbacher, Urs.** 2007. "z-tree: Zurich toolbox for ready-made economic experiments." *Experimental Economics*, 10(2):171–178.

- [16] **Gächter, Simon, Stefan Grosse, and Bettina Rockenbach.** 2009. “A dynamic public-good experiment.” Working paper, University of Erfurt.
- [17] **Gächter, Simon, and Benedikt Herrmann.** 2009. “Reciprocity, culture and human cooperation: previous insights and a new cross-cultural experiment.” *Philosophical Transactions of the Royal Society B: Biological Sciences* 364:791–806.
- [18] **Gächter, Simon, Elke Renner, and Martin Sefton.** 2008. “The long-run benefits of punishment.” *Science*, 322(5907):1510.
- [19] **Greiner, Ben.** 2004. “An online recruitment system for economic experiments.” In Kremer, K. and Macho, V., editors, *Forschung und wissenschaftliches Rechnen 2003*, 63:79–93. Ges. für Wiss. Datenverarbeitung, Göttingen.
- [20] **Güerker, Özgür, Bernd Irlenbusch, and Bettina Rockenbach.** 2006. “The competitive advantage of sanctioning institutions.” *Science*, 312:108–111.
- [21] **Levati, M. Vittoria, Matthias Sutter, and Eline van der Heijden.** 2007. “Leading by example in a public goods experiment with heterogeneity and incomplete information.” *Journal of Conflict Resolution*, 51(5):793–818.
- [22] **Nikiforakis, Nikos** (2008). “Punishment and Counter-Punishment in Public Good Games: Can we really govern ourselves?” *Journal of Public Economics* 92:91–112.
- [23] **Nikiforakis, Nikos, and Hans-Theo Normann.** 2008. “A comparative statics analysis of punishment in public-good experiments.” *Experimental Economics*, 11(4):358–369.
- [24] **Nikiforakis, Nikos, Hans-Theo Normann, and Brian Wallace.** (forthc.). “Asymmetric enforcement of cooperation in a social dilemma.” *Southern Economic Review*, 25:69–89.

- [25] **Noussair, Charles, and Cindy Soo.** 2008. "Voluntary contributions to a dynamic public good: Experimental evidence." *Economics Letters*, 98(1):71–77.
- [26] **de Quervain, Dominique J.-F., Urs Fischbacher, Valerie Treyer, Melanie Schellhammer, Ulrich Schnyder, Alfred Buck, and Ernst Fehr.** 2004. "The Neural Basis of Altruistic Punishment." *Science* 305:1254–1258.
- [27] **Reuben, Ernesto, and Arno Riedl.** 2009. Enforcement of contribution norms in public good games with heterogeneous populations. *Working Paper*.
- [28] **Richerson, Peter J., and Robert Boyd.** 2005. *Not by Genes Alone*. The University of Chicago Press, Chicago and London.
- [29] **Sadrieh, Abdolkarim, and Harrie A. A. Verbon.** 2006. "Inequality, cooperation, and growth: An experimental study." *European Economic Review*, 50:1197–1222.
- [30] **Sefton, Martin, Robert Shupp, and James Walker.** 2007. "The Effect of Rewards and Sanctions in Provision of Public Goods." *Economic Inquiry*, 45(4):671–690.

A Instructions to the experiment

General information

- This experiment consists of **20 rounds** with **2 stages** each.
- At the beginning of the experiment, you will be assigned to one of the groups of four participants each. During the whole experiment, you will interact only with the members of your group. However, at no time, you will be informed about the identities of your group.
- You will be assigned an **identity letter**: R, S, T, or U that will be kept constant during the whole experiment.
- At the beginning of the experiment, 18 experimental tokens, (your **starting endowment**), will be assigned to your experimental (wealth) account. Additionally, in each round you will receive a **round endowment** of 2 tokens. Hence, your **wealth account** in the very first round consists of the starting endowment of 18 tokens and the round endowment of 2 tokens, i.e., 20 tokens in total. In each of the following rounds, your wealth account will be equal to your wealth account that you reach at the end of the previous round plus the actual round endowment of 2 tokens.

Course of Action

Stage 1: Contributing to the Project. In stage 1 of each round, you have to decide how many tokens from your wealth account you are going to contribute to the project. The remaining tokens will be kept by you. You can only contribute integer number of tokens. The earnings from the project are calculated according to the same formula for each group member. Please note: *Each* group member receives the same earnings from the project, i.e., each group member benefits from *all* contributions to the project.

Your wealth after Stage 1

Your wealth after Stage 1 consists of two parts:

Thus, your wealth account after Stage 1 amounts to:
Your wealth at the beginning of Stage 1 – your contribution to the project
+ 1.6 * sum of the contributions of all group members / 4

- tokens you have kept = your wealth at the beginning – your contribution to the project
- earnings from the project = 1.6 * sum of the contributions of all group members / number of group members

Some examples for the calculation of your wealth after Stage 1

Your wealth account	20	32	63	15
Your contribution to the project	7	17	52	3
Sum of the contributions of other group members	25	21	18	37
Your earnings from the project	$51.2 / 4$ $= 12.8$	$60.8 / 4$ $= 15.2$	$112 / 4$ $= 28.0$	$64 / 4$ $= 16.0$
You kept from your wealth account	$20 - 7$ $= 13.0$	$32 - 17$ $= 15.0$	$63 - 52$ $= 11.0$	$15 - 3$ $= 12.0$
Your wealth at the end of Stage 1	25.8	30.2	39.0	28.0

Stage 2: Possibility of reduction. In stage 2 you will be informed (sorted by identity letters) how much each group member contributed to the project and how much her current wealth is. You have to decide whether you assign tokens to other group members. You can assign tokens to each of your group members. Each negative token you assign to a group member reduces her wealth payoff by 1 token. If you assign no tokens to a group member her wealth won't change. Your costs for the assignment of tokens depend on the number of tokens you assign, as depicted in the following table:

You can also assign tokens greater than depicted in the table, i.e., 76, 77, etc. You can calculate your assignment costs for tokens greater than 75 by entering the desired token number on Stage 2 in the respective cell on the computer screen and press the button "calculate my costs".

Limitations: You can only assign tokens, if you are able to pay the assignment costs from your wealth account. You cannot reduce the earnings of other group members not more than to zero. If you assign tokens more than it would be sufficient to reduce the earnings of the target group member to zero, you nevertheless have to pay for the whole reduction. The earnings of the target member are reduced only to zero though. If you assign tokens to others and receive some tokens from other group members simultaneously, under certain circumstances your wealth account may get negative. You may, however, balance this negative account over the rounds.

Tokens you assign to a group member	Your as- signment costs	Tokens you assign to a group member	Your as- signment costs	Tokens you assign to a group member	Your as- signment costs
1	0.33	26	17.45	51	83.33
2	0.67	27	18.84	52	87.64
3	1.01	28	20.31	53	92.11
4	1.37	29	21.86	54	96.73
5	1.73	30	23.50	55	101.52
6	2.11	31	25.23	56	106.47
7	2.50	32	27.05	57	111.60
8	2.92	33	28.97	58	116.89
9	3.36	34	30.99	59	122.36
10	3.83	35	33.10	60	128.00
11	4.33	36	35.33	61	133.82
12	4.86	37	37.66	62	139.83
13	5.43	38	40.10	63	146.02
14	6.04	39	42.66	64	152.41
15	6.69	40	45.33	65	158.98
16	7.38	41	48.13	66	165.75
17	8.12	42	51.04	67	172.71
18	8.92	43	54.09	68	179.88
19	9.76	44	57.26	69	187.25
20	10.67	45	60.56	70	194.83
21	11.63	46	64.00	71	202.62
22	12.66	47	67.58	72	210.62
23	13.75	48	71.30	73	218.84
24	14.91	49	75.16	74	227.28
25	16.15	50	79.17	75	235.94

Please note: The costs for the assignment of tokens to different group members are calculated separately. For example: If you assign 25 tokens to each of the three members, your costs amount to $3 \times 16.15 = 48.45$ and not 235.94, which gives the costs of assignment if you assign 75 tokens to one single group member.

Your wealth at the end of the round

Your wealth at the end of the round consists of the following parts:

- your wealth account after Stage 1
- minus your costs of assignment for the tokens you assigned
- minus the reductions caused by the tokens assigned by other group members to you

Hence, in total:

<p>Your wealth after Stage 2 (Your wealth at the end of the round) =</p> <p style="margin-left: 40px;">Your wealth account after Stage 1</p> <p style="margin-left: 40px;">– minus your costs of assignment for the tokens you assigned</p> <p>– minus reductions caused by the tokens assigned by other group members to you</p>
--

Information

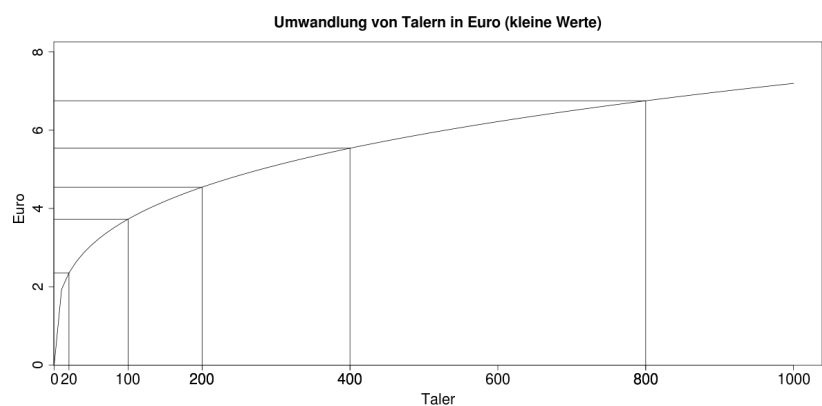
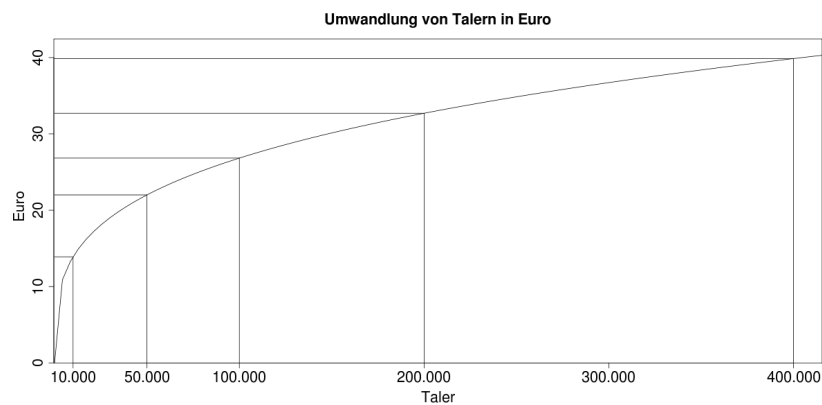
At the end of each round you will be informed about

- the wealth accounts of all members of your group
- the contributions of all your group members,
- the wealth accounts of all group members after Stage 1
- the tokens each group member received from other members (but you will not know who assigned these tokens) and
- the wealth accounts of all group members after Stage 2

After the feedback, the next round begins.

At the end of the experiment your wealth account will be transformed into Euros according to the following formula: Your earnings in Euro = (Your wealth in tokens)^{2/7}

Hence, your cash earnings will lie between 0,00 Euros and 40,00 Euros.



You have now a couple of minutes of time to go over again the instructions. If you should have some questions, please do not hesitate to inform us by raising your hand. In this case we will come in to your cabin to clarify the question. Please note that any kind of communication with other participants is prohibited.

We wish you success!

B Proof of existence of the equilibrium proposed for the *dynNOpun* game (intended for online publication only)

Consider a group of n players, interacting over T rounds in the *dynNOpun* game as presented in the main part of the paper. In this appendix, we set out to show that under relatively mild conditions, there is a class of equilibria with positive contribution levels if there are ν conditional cooperators, with $\nu = \min\{j \in \mathbb{N} | j > (1 - \mu)/\mu\}$, and k money-maximizing players, $k = n - \nu$, where conditional cooperators and money-maximizers are defined as in Fehr and Schmidt (1999). In fact, these equilibria may exist even for $k/(n - 1) > \mu/2$, in which case Fehr and Schmidt (1999) have shown that in the standard non-repeated linear public-good game, no equilibrium with positive contributions exists despite the presence of players with social preferences.

In these equilibria, all money-maximizers choose a symmetric contribution x_{mm}^t , up to an arbitrary round $T - t'$, and zero-contributions ever after. On the equilibrium path, the ν conditional cooperators always mirror the money-maximizers' behavior from the respective preceding round. The equilibrium yielding the highest – and symmetric – payoffs for all players is given by $t' = 1$ and $x_{mm}^t = E_{mm}^t, \forall t \leq T - t'$, where E_{mm}^t is the money-maximizers' round- t contribution capability. By a similar refinement argument as employed by Fehr and Schmidt (1999), we shall focus our attention on this particular equilibrium in the following.

Before we formulate our main proposition, we will introduce lemma 1 that will be helpful in our proof of the proposition.

Lemma 1. *If a conditionally cooperative player i is the single wealthiest player in her group, she will choose to equalize payoffs with the next-wealthiest player (independent of whether this is a single player or a group), provided her coefficient for disadvantageous inequality, β_i , fulfills*

$$\beta_i < \frac{n-1}{n-3}(1-\mu). \quad (2)$$

Proof. It does not pay for the conditional cooperator to contribute less than necessary to equalize payoffs with the next-wealthiest player, as any token contributed to the public good makes her lose $(1 - \mu)$ in monetary terms, but gains her $\beta_i/(n - 1)$ utility units for each player who is less wealthy than herself. Given she is the wealthiest person in the group, her total gains are β_i units for each token contributed. By definition, a player is a conditional cooperator if and only if $\beta + \mu > 1$ holds.³³ To contribute more than would be necessary to equalize payoffs with a group of n' next-wealthiest players, with $1 \leq n' \leq n - 1$, her additional monetary loss from contributing an additional token, $(1 - \mu)$, plus her utility loss from disadvantageous inequality *vis-à-vis* the n' formerly next-wealthiest players, $n'\alpha_i/(n - 1)$, would have to be less than her utility gains from advantageous inequality with respect to the remaining players in the group, $\frac{(n-1-n')\beta_i}{n-1}$. We require that this is not the case. Clearly, this requirement is strongest for $n' = 1$. Simple calculus shows that this requirement holds as long as

$$(1 - \mu)(n - 1) > (n - 2)\beta_i - \alpha_i. \quad (3)$$

However, given the model by Fehr and Schmidt (1999) specifies $\beta_i \leq \alpha_i$, it is obvious that inequality (2) is sufficient for (3) to hold. \square

Note that in our experiment, $n = 4$ and $\mu = 0.4$. Thus, inequality (2) reads as $\beta_i < 1.8$. By construction of the model of Fehr and Schmidt (1999), $\beta_i \leq 1$. Therefore, the requirement (2) obviously will be met for any player conforming to the model.

Proposition 1. *Let a group of n members consist of ν conditional cooperators and k money-maximizing players, where $\nu = \min\{j \in \mathbb{N} | j > (1 - \mu)/\mu\}$ and $k = n - \nu$. Then, the following conditions are sufficient (yet not necessary) for positive-contribution equilibria to exist:*

(I) $k \geq (n - 1)\mu/(1 - \mu)$,

(II) $\mu \geq 1/(n - 1)$, and

³³Cf. Fehr and Schmidt (1999).

(III) $\beta_i < \frac{n-1}{n-3}(1 - \mu)$ for all ν conditional cooperators.

In these equilibria, a conditionally cooperative player does not contribute if there is a player wealthier than herself, nor if all players have the same wealth levels. If there are players who are less wealthy than the conditional cooperator, she chooses her contributions such as to equalize wealth levels with the wealthiest money-maximizing player if that player did not contribute a positive amount, or with the next-wealthiest conditional cooperator having a different wealth level than herself, whoever of the two is wealthier.

The k money-maximizers always contribute fully to the public good in periods 1 to $T - 1$, as long as all ν conditional cooperators stick to their equilibrium strategy. Otherwise, the money maximizers stop contributing.

This gives rise to the following behavior on the equilibrium path: all k money-maximizers always contribute fully to the public good in periods 1 to $T - 1$, while the conditionally cooperative players always contribute the amount necessary to equalize wealth levels in case the money-maximizing players failed to contribute in the current round. This amount is exactly the amount contributed by the money-maximizing player in the preceding round. In other words, if all k money-maximizers are endowed with a given wealth level E_k^t and all conditional cooperators had a level of E_ν^t on their accounts in any given round $t, t \leq T - 1$, then the former (latter) would contribute $x_k^t = E_k^t$ ($x_\nu^t = E_\nu^t - E_k^t = E_k^{t-1}$; note that $E_\nu^t > E_k^t$ must hold for the latter to contribute a positive amount, which is fulfilled in the proposed equilibrium). In the final round, money maximizers do not contribute, and conditional cooperators contribute as to equalize payoffs over all players.

Proof. First of all, consider a money-maximizing player j . Obviously, in the final round this player does not have an incentive to deviate from her equilibrium strategy, as the final round is equivalent to a one-shot linear public-good game and in this class of games, free-riding is a dominant strategy. Next, we show that a money-maximizing player j does not have an incentive to deviate from her equilibrium strategy in round $T - 1$. Given their equilibrium strategy, all ν conditionally cooperative players will choose to contribute in round T any amount contributed by the least-contributing

money-maximizer in round $T - 1$, as this leads to an equalization of payoffs with the latter. At the same time, all money-maximizing players other than j will choose to contribute everything on their current account. If j chooses to deviate, she will therefore determine conditional cooperators' choices in round T . Therefore, contributing in $T - 1$ will pay off if and only if the gain from reducing her contribution by a single token, $(1 - \mu)$, is smaller than the gains from conditional cooperators' subsequent matching contributions, $\nu\mu$. This condition is equivalent to $\nu > (1 - \mu)/\mu$, which is true by the definition of ν in proposition 1. In fact, this argument holds for any round t , given the least-contributing money-maximizer's contributions are always matched by conditional cooperators in $t + 1$.

Now, consider a conditionally cooperating player i . To answer the question of whether she has an incentive to deviate from the equilibrium strategy, we start with an analysis of the final round. In round T , the proposed equilibrium strategy leads to an equal distribution of wealth. If condition (III) holds, we know by lemma 1 that no conditional cooperator has an incentive unilaterally to provide less than the prescribed level, as she will maximize her utility by contributing as much as necessary to equalize payoffs with respect to the second-wealthiest individual. On the other hand, a conditional cooperator does not have an incentive unilaterally to provide more than prescribed by the equilibrium strategy, given this would leave the cooperator worse off both in monetary terms and in terms of (disadvantageous) inequality.

What the preceding paragraphs have shown is that (i) money-maximizers do not have an incentive to deviate from the strategy prescribed by proposition 1 throughout the game, and (ii) conditional cooperators do not have an incentive to deviate from their prescribed strategy in round T . What remains to be shown is that the latter do not have an incentive to deviate in earlier rounds. First of all, consider a single conditional cooperator providing q tokens less than prescribed in round $T - 1$. While this deviation will not change the behavior of money-maximizing players given their round- T contributions will be zero irrespective of what other players do, it will lead to defection also on the part of the remaining players. In this situation, by lemma 1 the deviating player's best response will be to provide q tokens in the final round.

By doing so, the final situation will be the same as the situation before the final round under equilibrium play. The difference between this situation and the equilibrium outcome is that conditional cooperators are better off than money-maximizers in monetary terms, namely by the latters' round- $(T - 1)$ contributions. This leads to a utility gain compared to the equilibrium of $(1 - \nu\mu)x_{\kappa}^{*,T-1} - \frac{k}{n-1}\beta_i x_{\kappa}^{*,T-1}$, where $x_{\kappa}^{*,T-1}$ is a money-maximizer's equilibrium contribution in $T - 1$. For the strategy profile proposed in proposition 1 to be an equilibrium, this term must not be positive, which is equivalent to requiring

$$\frac{k}{(n-1)} \geq \frac{(1 - \nu\mu)}{\beta_i}, \quad (4)$$

for all ν conditional cooperators. The lowest-possible β_i is $\beta_i = 1 - \mu$, by definition of a conditional cooperator. Substituting this into inequality (4), we obtain

$$k \geq (n-1) \frac{1 - \nu\mu}{1 - \mu}.$$

This requirement will obviously be fulfilled for the parameter values used in our experiment, given it corresponds to condition (I) from the proposition under the smallest-possible value of ν , $(1 - \mu)/\mu$.

The next question to be answered is whether a conditional cooperator has an incentive to 'under-provide' relative to her prescribed strategy in an earlier round. In this case, she would deter further contributions from both money-maximizers and conditional cooperators, herself only closing the resulting wealth gap *vis-à-vis* the other cooperators. The resulting payoffs correspond to the equilibrium current wealth levels of that round in case the conditional cooperator had not deviated. In other words, by contributing less than prescribed, a conditional cooperator can fix the payoff vector at the equilibrium current wealth level of a given round. We know from the above that the conditional cooperator prefers the equilibrium outcome to the current wealth levels before the final round. What we have to show is that she also prefers the equilibrium outcome to the equilibrium current

wealth levels at the end of any round $t, t < T$. We do this by showing that she, in fact, always prefers equilibrium current wealth levels in $t + 1$ to those in $t, t < T - 1$ (recall that we have already shown this for $t = T - 1$).

Denote by E_m^t (E_c^t) the equilibrium contribution capabilities of a money-maximizing (conditionally cooperative) player, and by \mathbf{E}_m^t and \mathbf{E}_c^t the corresponding capability vectors. Note that, in equilibrium, $E_c^t = E_m^t + E_m^{t-1}$ must hold. Given their prescribed strategies in rounds $t < T - 1$, all money-maximizers will choose $x_m^t = E_m^t$, while the conditional cooperators will choose $x_c^t = x_m^{t-1} = E_m^{t-1}$. The resulting end-of-round wealth levels will be $E_m^{t+1} = \mu k E_m^t + \mu \nu E_m^{t-1}$ and $E_c^{t+1} = E_m^{t+1} + E_m^t$. All we have to show now is that a conditional cooperator i 's utility from a payoff vector $\mathbf{E}^t = (\mathbf{E}_m^t, \mathbf{E}_c^t)$, $U_i(\mathbf{E}^t)$ is smaller than her utility from the payoff vector \mathbf{E}^{t+1} . This is equivalent to requiring

$$U_i(\mathbf{E}^{t+1}) = E_m^{t+1} + E_m^t - \frac{k}{n-1}\beta_i E_m^t > E_m^t + E_m^{t-1} - \frac{k}{n-1}\beta_i E_m^{t-1} = U_i(\mathbf{E}^t)$$

$$\Leftrightarrow E_m^{t+1} - E_m^{t-1} - \frac{k}{n-1}\beta_i(E_m^t - E_m^{t-1}) > 0,$$

which by $E_m^{t+1} = \mu k E_m^t + \mu \nu E_m^{t-1}$ and, consequently, $E_m^t = \mu k E_m^{t-1} + \mu \nu E_m^{t-2}$ leads to

$$(\mu k)^2 E_m^{t-1} + \mu^2 k \nu E_m^{t-2} + \mu \nu E_m^{t-1} - E_m^{t-1} - \frac{k}{n-1}\beta_i(\mu k E_m^{t-1} + \mu \nu E_m^{t-2} - E_m^{t-1}) > 0. \quad (5)$$

Reorganizing (5) yields

$$k\left(\mu - \frac{\beta_i}{n-1}\right)(\mu k E_m^{t-1} + \mu \nu E_m^{t-2}) + (\mu \nu - 1)E_m^{t-1} + \frac{k}{n-1}\beta_i E_m^{t-1} > 0. \quad (6)$$

In the following, we show why inequality (6) will always be fulfilled under the conditions specified in the proposition. Consider first the sum of the second and third terms on the left-hand side of the inequality. By definition of ν ,

$\mu\nu - 1 \geq -\mu$, and therefore,

$$(\mu\nu - 1)E_m^{t-1} + \frac{k}{n-1}\beta_i E_m^{t-1} \geq E_m^{t-1} \left(\frac{k\beta_i}{n-1} - \mu \right). \quad (7)$$

Under condition (I) from the proposition, it can be easily seen that the right-hand side of (7) will be larger or equal to zero even for the smallest-possible β_i a conditional cooperator can have, i.e. $\beta_i = 1 - \mu$. Let us now turn to the first term in (6). Obviously, this term will be positive if $\mu - \beta_i/(n-1) > 0$ for all possible values of β_i . In constructing their model, Fehr and Schmidt (1999) introduced the restriction that $\beta_i \leq 1$. Substituting the maximum-possible value for β_i , we directly obtain condition (II) from the proposition. In other words, under the conditions specified in proposition 1, the sum on the left-hand side of inequality (6) will always be positive. Thus, a conditional cooperator will never have an incentive to deviate contributing less than under the equilibrium strategy, thereby inducing a payoff vector that equals the equilibrium wealth-level vector of any earlier round $t, t < T$. Note that in our derivations, we have used a number of conservative approximations. Therefore, the true parameter space for which the equilibrium exists, will be larger than our conditions suggest.

What remains to be shown is that no conditionally cooperating player has an incentive to contribute more than specified by the equilibrium strategy prescribed by proposition 1. We have already done so for the final period. Consider period $T - 1$. If a conditionally cooperating player contributes more than prescribed in our proposition, this will not have any effect on money-maximizers' behaviour, given the latter will not contribute any positive amounts in the final round independent of her choice. If the player contributes to her full capacity, she is equally well off as any money-maximizer. In the final period, the remaining conditional cooperators will equalize wealth levels, such that no inequality will arise. Furthermore, the resulting wealth levels will be as high as in the equilibrium, such that the conditional cooperator will be equally well off, given the only change is the point in time when reciprocation happens. To see this, note that nothing out of the returns from the 'over-contributed' amount is used for contributions, as contributions are

determined by the wealth difference between money-maximizers and conditional cooperators. This difference, however, is not affected by the deviating player's contribution. While this means that the strategy prescribed by our proposition is (at best) a weak best-response, this does not affect the existence of the proposed equilibrium. If, on the other hand, the deviating cooperator chooses less than her full capability, there are two possibilities. If there are still more than one conditional cooperators left, they stop to contribute by lemma 1, as the next-wealthy player will be one of their peers. If only one conditional cooperator is left, she will choose to equalize wealth levels with the deviating cooperator, evidently being next-wealthy player. However, this will diminish her final-period contribution. Consequently, the final payoff allocation would leave the deviating player worse off in monetary terms, at the same time inducing inequality. Clearly, following the equilibrium strategy gives the player a higher utility.

Finally, consider any period $T - t', t' \geq 2$. If a conditional cooperator contributes more than specified in proposition 1, an argument that is analogous to the one presented in the preceding paragraph shows that the conditional cooperator cannot induce a payoff vector that leaves him better off than the wealth-level vector that would result in equilibrium after period $T - t' + 1$. However, in our discussion of the case of 'under-provision' on the part of a conditional cooperator, we have seen two things: given all other players follow their equilibrium strategy, a conditional cooperator can always induce a payoff vector that is equal to the equilibrium wealth-level vector after any arbitrary period; and the cooperator will never do so, as doing so would never leave him better off under the conditions specified in the proposition. Therefore, a conditional cooperator cannot possibly reach a higher utility level than in equilibrium by contributing more than specified in the equilibrium strategy. Evidently, this holds for all rounds $t, t \in \{1, \dots, T\}$. \square

Remark: The threat of money-maximizing players stopping to contribute in response to over-contributions by conditional cooperators is not as incredible as it may seem at first sight. The number of conditional cooperators in our equilibrium, ν , has been specified to be minimal with respect to

the number of cooperators necessary to make contributions in a given period $t, t < T$, pay off for money-maximizing players. If one of these cooperators contributes fully in period t , the cooperator will no longer match the money-maximizers' contributions in $t + 1$. Given ν is 'minimal' in the sense specified above, the money-maximizer would be better off free-riding in t . Therefore, for the equilibrium to exist, conditional cooperators must not destroy the money-maximizers' incentives for cooperation stemming from the formers' reciprocity by 'over-contributing' early on.

C Additional regression results, overview figures for individual groups (intended for on-line publication only)

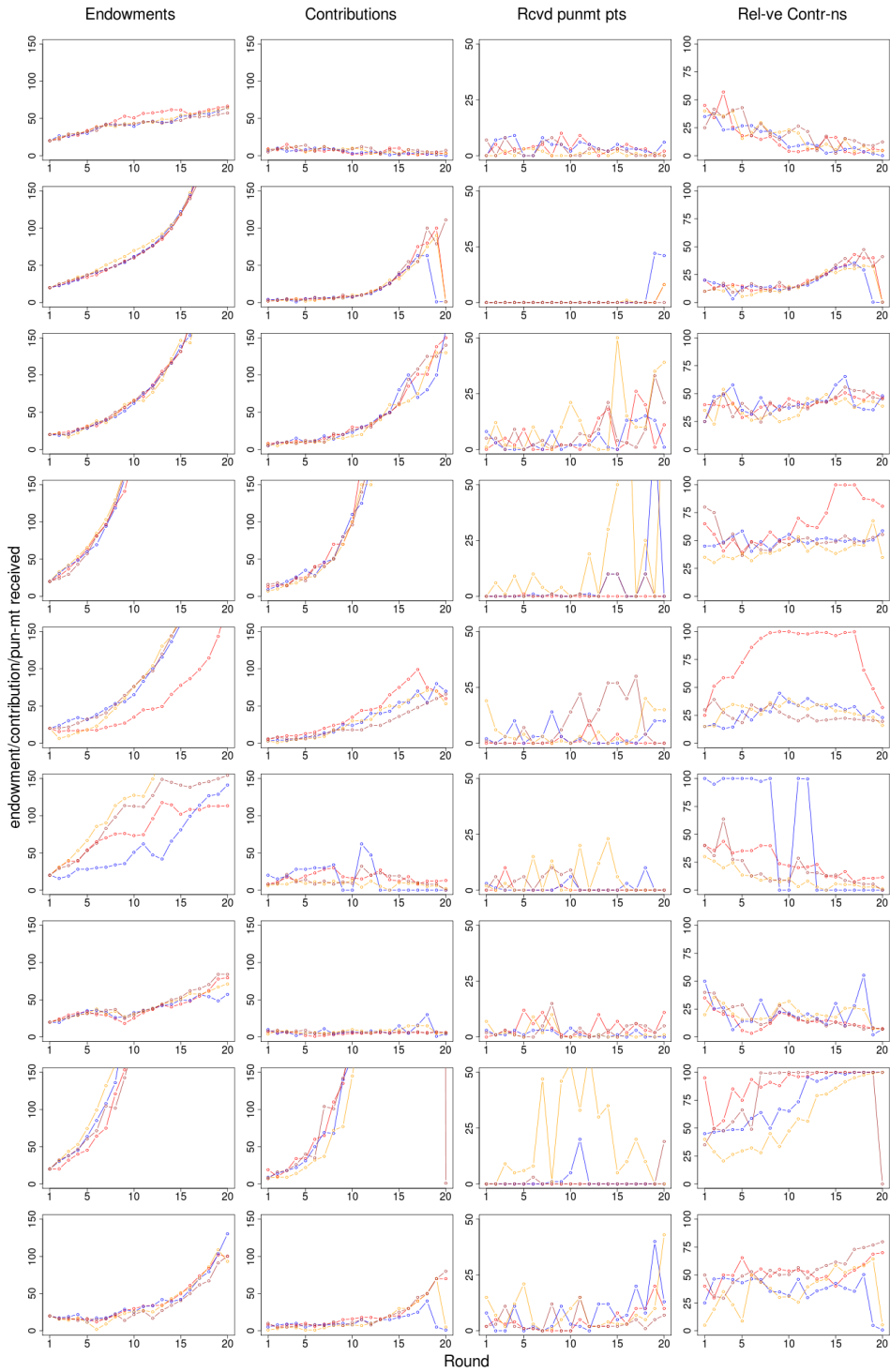


Figure C.1: Overview of the data from individual groups in the *dynPUN* treatment.

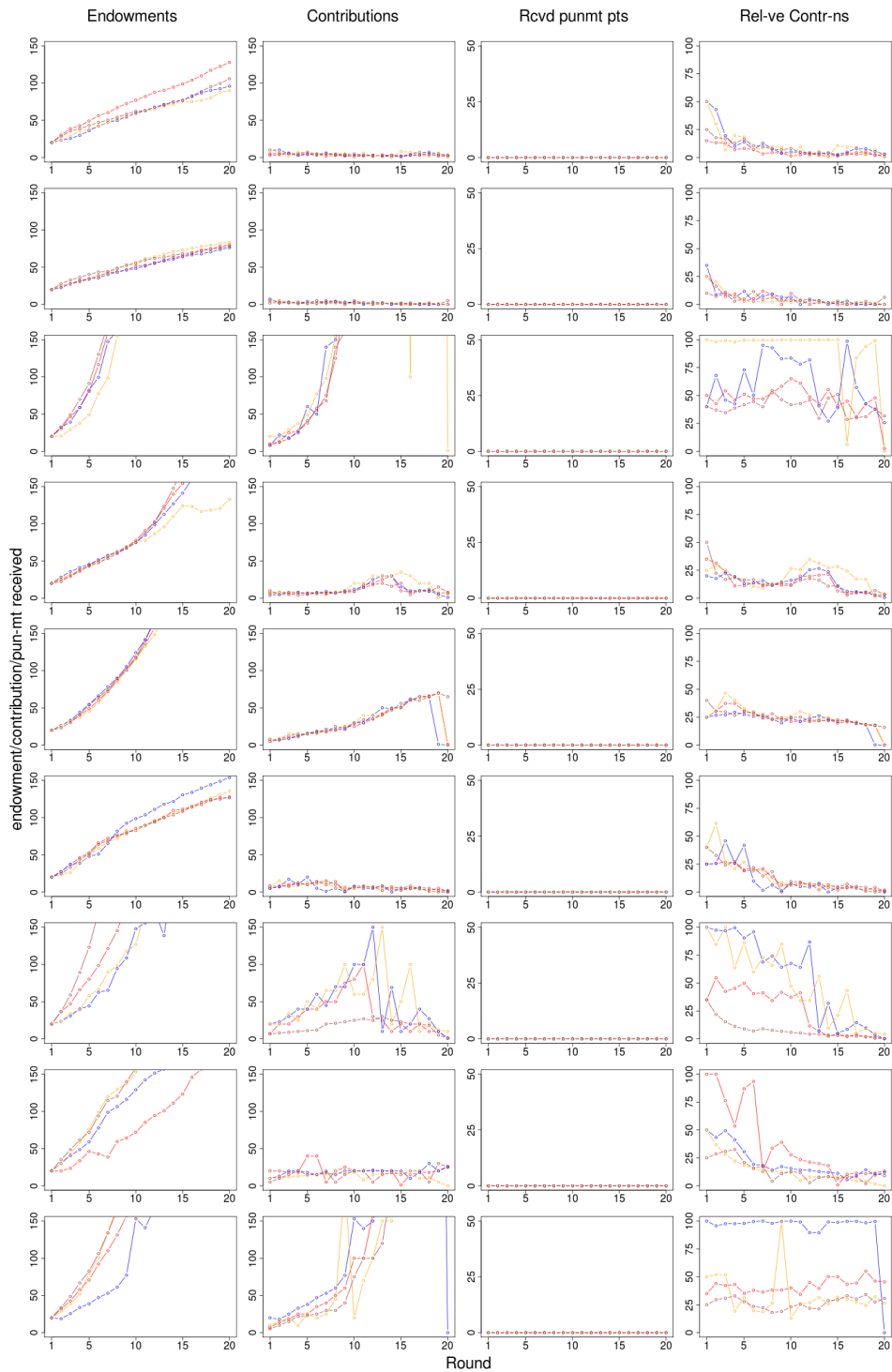


Figure C.2: Overview of the data from individual groups in the *dynNOpun* treatment. The third column is, of course, superfluous. We included it for easier comparison with the data from *dynPUN*.

Table C.1: Regression for the models from Table 2, extended by an interaction term for period and the endowment variation coefficient.[†]

Variable	<i>dynPUN</i>	<i>dynNOpun</i>
Positive deviation from the average relative contribution in $t - 1$	-0.1732 (0.1199)	-0.1679. (0.0934)
Negative deviation from the average relative contribution in $t - 1$	-0.0071 (0.0901)	0.2415 (0.1743)
Positive deviation from the average capability in $t - 1$, normalized [‡]	-0.0101 (0.0179)	-0.0251 (0.0372)
Negative deviation from the average capability in $t - 1$, normalized [‡]	0.0863 (0.0747)	0.1798*** (0.0454)
Positive deviation from the average surplus from the public good in $t - 1$, normalized [‡]	0.0094 (0.0081)	0.0030 (0.0063)
Negative deviation from the average surplus from the public good in $t - 1$, normalized [‡]	-0.0580*** (0.0172)	-0.0710* (0.0309)
Dummy: having been punished in $t - 1$	0.0008 (0.0123)	
Received punishment as a fraction of the current wealth level in $t - 1$	0.1933** (0.0660)	
Variation coefficient of the group's current contribution capabilities	0.1388* (0.0662)	-0.1584 (0.1163)
Period	-0.0009 (0.0016)	0.0014 (0.0016)
Period * Variation coefficient of the group's current contribution capabilities	-0.0151* (0.0063)	0.0062 (0.0092)
Logarithm of the group's average contribution capability	0.0095* (0.0046)	-0.0081 (0.0110)
Constant	-0.0438* (0.0224)	0.0259 (0.0371)

[†] Significance levels are indicated as follows: *** 0.001, ** 0.01, * 0.05, . 0.1.

[‡] Deviations are normalized by division by the average contribution capability and average surplus, respectively.