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

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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. If past payoffs determine present contribution capabilities, this may be devastating. Groups may fall prey to a poverty trap or, to avoid this, abstain from punishment altogether. In an experimental study of dynamic public good provision we show that although single groups do succumb to the above-mentioned hazards, neither is the case generally. By continuously contributing larger fractions of their wealth, groups with punishment possibilities achieve increasing wealth increments, while increments fall when punishment possibilities are absent.

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

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shared food, voting under democratic regimes, or preventing climate change. The critical issue in each 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 (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. Present 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. Alternatively, capabilities may be high after 'successful free-riding': if a local government free-rides on others' investment into a durable public good like inter-regional infrastructure, investing instead in local public goods that benefit the productivity only of the local industry, it may increase its future tax base and thus, its capabilities to provide any kind of public goods in the future. In the limit, free-riders accumulate resources on their private accounts while past providers may not be *able* to contribute in the future due to others' excessive free-riding.

Although there is a considerable literature on cooperation in social dilemmas (cf., e.g., the reviews in Fehr and Fischbacher, 2003; or Gächter and Herrmann, 2009), our knowledge about cooperative behavior in dynamic social-dilemma games is limited. With this study, we contribute to a small but rapidly growing body of experimental literature on this issue. 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 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 sum of period payoffs, but it is given by the final amount on their wealth account.[2]

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

[2]An interesting related study is that of Buckley and Croson (2006) who analyse the effect of information about the group members' accumulated wealth levels on contribution

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; Gürerk, et al., 2006; or Sefton et al., 2007). Alternatively, potential punishers, being aware of this hazard, might refrain from sanctioning. 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 punishment possibilities as compared to groups that do not dispose of such possibilities. Groups with punishment possibility 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. 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 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.

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, until recently, experimental studies on social dilemmas focusing on dynamics other than repeated-

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.

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

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

game effects were surprisingly limited.[5]

Noussair and 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. Sadrieh and 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. 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.

Gächter et al. (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. They analyze the role of the dynamics and separate the effects of inequality, rising endowments, and endogeneity of evolving wealth levels. In contrast to our study, final payoffs are still given by the sum of all period payoffs. Unlike in the study of Noussair 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.

Battaglini et al. (2010) examine behavior in a durable-public-good setting. Their setup is close to ours except for a number of parameter choices and the fact that in their study, payoffs are given by the sum of period payoffs; only the public-good stock carries over from one period to the next. Furthermore, their focus lies on whether agents play (efficiency-enhancing) trigger strategies, and how behavior is influenced by whether decisions are made independently or by some political mechanism such as majority voting. They find that even though there are equilibria sustaining high levels of cooperation in their game, the decentralized institution yields little cooperation

[5] An early exception is Rapoport (1988) who examines how different information conditions affect behavior in a common-pool-resource game with depletion. He observes little cooperation, even though communication of an optimal strategy did have a positive effect on harvesting behavior.

as predicted by the Markov-equilibrium steady state. At the same time, a majority rule substantially increases the amount of cooperation, albeit not enough to achieve an efficient outcome.

In a recent study, Cadigan et al. (in press) investigate carry-over effects in a two-stage public-goods game. Similar to the results of Gächter et al. (2009), they find cooperation-inhibiting effects of introducing dynamically evolving contribution capabilities in all of their treatments. In one of their experimental settings, the payoffs in stage one determine the endowments in stage two. While in treatment NE subjects are paid after each of the two stages, in treatment PO subjects are paid only once (after stage two) – similar to our setting. In each of the five repetitions of the two-stage game – compared to first stage contributions – second stage contributions (absolute as well as relative) always decrease. The payoffs in PO are also lower than the payoffs in NE as well as the payoffs in their baseline treatment (a standard public goods game with 10 repetitions).

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.[6]

In the *dynNOpun* game, each round $t, t = 1, ..., T$, has exactly one stage

[6]This 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.

in which a standard public-good game with n players is played. In the first 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:

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

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:

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

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 $\Omega_i^0 \equiv E, \forall i$. Finally, players' payoff Π_i is given by $\Pi_i = \Omega_i^T$.

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, following directly from the typical backward-induction argument. In the subgame-perfect equilibrium, no player will make positive contributions, nor punish other players in case of the *dynPUN* game.

There is one notable difference between the games presented here and their repeated-game counterpart with fixed, recurring endowments. If in the repeated-game situation, an argument along the lines of Kreps et al. (1982) can be brought forward, the argument can be extended for our game. To see this, note that in our games, it may pay to contribute early on for a payoff-maximizing player *because contributions increase future contribution capabilities*. If others can be expected to contribute in later stages – be it because they follow a tit-for-tat strategy or simply because they are unconditionally altruistic – increasing their contribution capabilities at the same time will increase the source on which to free-ride later on. The important difference between the repeated game and our game is that contributing in early rounds is a best-response even to *unconditional* contributors.

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 this question, we resort to one of the most prominent and tractable social preference models, proposed by Fehr and Schmidt (1999). They show that in a standard linear public-good game, equilibria with positive contributions are possible if (some) players are inequality-averse. Furthermore, if punishment is possible on a second stage the restrictions on the model parameters for a cooperative equilibrium to ensue are considerably relaxed.

What does inequality-aversion imply for our dynamic game? We first address this question for the *dynNOpun* game. There are two classes of equilibria which closely correspond to the equilibria presented by Fehr and Schmidt (1999): (i) the omnilateral-defection equilibrium, and (ii) equilibria with completely symmetric contributions amongst a group of conditional cooperators who disregard potentially lower contribution levels by money-maximizing players. For the parameters used in our study, there may not be any money-maximizing players within the group. According to the estimates by Fehr and Schmidt (1999), such group compositions are very unlikely.[7]

However, for the *dynNOpun* game, there is yet a third class of equilibria that may sound counter-intuitive at first sight. In these equilibria, money-maximizing players start out contributing their full endowment, while con-

[7] The 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.

ditional 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 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.[8]

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*, it may be profitable for money-maximizing players to invest in the overall resource stock 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).[9] In other words, unlike in the 'static' game the existence of inequality concerns could often lead to a high degree of cooperation.[10]

For a public-good game with punishment opportunities, Fehr and Schmidt (1999) show that equilibria exist in which all players contribute

[8]In 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.

[9]For 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).

[10]In 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 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.

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".[11] 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.[12]

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 relatively high. 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 may 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 given by enforcer preferences rather than by players' wealth.[13]

On the other hand, for the class of positive-contribution equilibria in the

[11]Both p.842.

[12]For 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).

[13]For 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.

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.

2.3 Research hypotheses

Our first hypothesis reflects the "standard" game-theoretic prediction.

H 1. *Under common knowledge of money-maximizing preferences and rationality, we expect to observe no contributions and no punishment.*

Yet, the introduction of punishment opportunities enhances both the prospects of a cooperative outcome and the size of contributions in the repeated public-good games commonly used in the literature if parts of the population are motivated by social considerations. In contrast, in our game, the social-preference model proposed by Fehr and Schmidt (1999) predicts a substantial difference only in the achieved contribution levels. The predicted difference in the probability of an outcome with non-negligible cooperation rates tends to be rather small. This leads to research hypothesis 2.

H 2. *Under social preferences in the spirit of Fehr and Schmidt (1999), average contribution levels are expected to be higher in the treatment with punishment possibilities. However, the number of groups attaining high levels of cooperation are not expected to differ between treatments.*

Note that hypothesis 2 rests on equilibrium considerations that rely on a 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. However, we know from the vast amount of experimental evidence on public-good games with punishment that these conditions are fulfilled hardly ever.[14] 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

[14]For an overview, cf., e.g., Gächter and Herrmann (2009).

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.[15] 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 to prepare research hypothesis 3.

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 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.[16] 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

[15]Cf., e.g., Nikiforakis and Normann (2008). A notable exception is to be found in the study by Gächter, 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.

[16]Cf. 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).

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).

Scen 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, 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 benchmark scenario:

Scen 2. *Players in dynPUN abstain from contribution enforcement in order to save the own and 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.*

Both **Scen1** and **Scen2** constitute extreme scenarios of how peer-punishment may fail to promote the provision of a public good under endogeneously evolving contribution capabilities. Nevertheless, they illustrate working mechanisms that are plausible in light of the ample experimental evidence. Their gist is summarised in hypothesis 3.

H 3. *The average contribution and payoff levels in the treatment with punishment opportunities do not surpass those in the treatment without such opportunities.*

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."[17] 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 self-fulfilling. 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.[18] This is an important difference to the setting of Sadrieh 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.[19] 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., Anderson et al., 2007; Cherry et al., 2005, or the literature surveyed in Chan et al., 1999).[20] 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

[17] Levati et al. 2007, p. 812). For a study on heterogeneous punishment technologies, see Nikiforakis et al. (2010).

[18] Cherry et al. 2005 examine a different kind 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.

[19] Sadrieh and Verbon (2006, p. 1219).

[20] For 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).

return was set to $\mu = 0.4$, and punishment costs were calculated according to the following formula:

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

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 a certain power-asymmetry under heterogeneous wealth levels: in real-life situations, it may be virtually impossible for a below-average earner to drive a rich man into bankruptcy. Under a linear 1:3 technology, however, nothing would prevent that. 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 to reduce a punishment-related experimenter-demand effect as much as possible.

Our experiment was programmed in z-Tree (Fischbacher, 2007) and run at the Erfurt Laboratory for Experimental Economics (eLab). We ran 4 sessions, 2 for each of our treatments. A total of 72 subjects were recruited using ORSEE (Greiner, 2004). The instructions (see Appendix A) were handed out 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. We obtained 9 independent observations, i.e., matching groups, 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. This formula satisfies the "precept" of *saliency* as formulated by Smith (1982, p.930f.) and extensively discussed in Bardsley et al. (2010). However, it does so in a non-standard way. The reason for this choice is the following: a linear token-to-Euro ratio leads to one of two problems. A high linear exchange rate would make the experiment prohibitively costly, bearing in mind that the maximum number of tokens that could be achieved in the experiment exceeded 400'000, while too low a rate may violate the *dominance* "precept": incentives would be too low to make monetary payoffs an important concern.

Imagine, for a moment, the case of a 1000:1 ratio, corresponding to a maximum potential gain of 400 Euros (compared to an average hourly wage of a student research assistant of 7.50 Euros). Recall that subjects are endowed with 20 tokens, corresponding to 2 Cents in our example. This could lead to a false perception by the subjects that their decisions throughout the experiment must result in a very small final payment. Additionally, for a subject to obtain the hourly wage of a student assistant under this exchange rate, it would need 13 (out of 20) rounds of full cooperation if all players would cooperate right from the start.[21] In other words, for the monetary payoff from the experiment to be considered meaningful, we would have needed to increase a linear token-to-ratio even further. For groups under a linear exchange rate to reach the hourly-wage equivalent as under the scheme actually used, the ratio would have needed to be as high as 125:1, with a maximum gain of 3'200 Euros per subject.

Having laid out the reasons for why it is *necessary* to have a non-linear exchange rate, let us state briefly why we hold it is *admissible* to do so. Our perspective follows the spirit of Cubitt, Starmer, and Sugden's (1998, p. 116) *isolation hypothesis* that a subject treats every task within a multiple-task experiment "as if it were the only task, and for real". Cubitt et al. (1998) develop their hypothesis in the context of the random-lottery incentive scheme in which only one out of several tasks is paid and this task is selected randomly. Bardsley et al. (2010, p. 270) go one step further suggesting that the hypothesis also holds in the binary-lottery incentive scheme –in which tokens are translated into lottery tickets for a "grand lottery" to be played out at the end– thereby providing a ready explanation for evidence from binary-lottery scheme experiments that the scheme seems to induce higher risk aversion in subjects rather than inducing risk neutrality (as it should under the expected-utility hypothesis). In this view, subjects treat the experimental task as if the lottery tickets were monetary payoff, abstracting from the fact that there is an additional intermediating mechanism. If the hypothesis holds, we may expect subjects also to abstract from *conversion formulas* for tokens as an additional layer of situational complexity. Of course, this can be expected to motivate subjects only if *dominance* holds, that is, if it is made clear at the outset that there is a substantial monetary incentive to do well in the experiment. In our experiment, this was stressed by a clear reference to the maximum potential earnings of 40 Euros in the instructions.

The sessions lasted approximately three quarters of an hour, average pay-

[21] For comparison: under our payoff scheme, 20 tokens translate to 2.35 Euros, and it would take 8 rounds of full cooperation to obtain the equivalent to an hour's wage of a student assistant.

ments 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 can be seen in figure 2, we can clearly reject hypothesis **H1**. In line with the previous literature, subjects contribute positive amounts to the public good in both treatments. In addition, figure 3 shows that subjects do invest in punishment when given the opportunity.

4.1 Performance and aggregate behavior

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. In the first (second) quarter of the experiment, in *dynPUN* wealth levels are (weakly) significantly lower than in *dynNOpun* (p-values by quarters are 0.0142, 0.0939, 0.2581, and 0.7304). In contrast to benchmark scenario **SCEN1**, final payoffs are not statistically different ($p = 0.6914$).[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.*

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*; the figures are averages over group averages of final wealth as a fraction of the socially optimal level). 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. Does that mean our benchmark scenario **SCEN2** is correct in that the treatments do not differ at all? The answer is no. To start with, 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

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

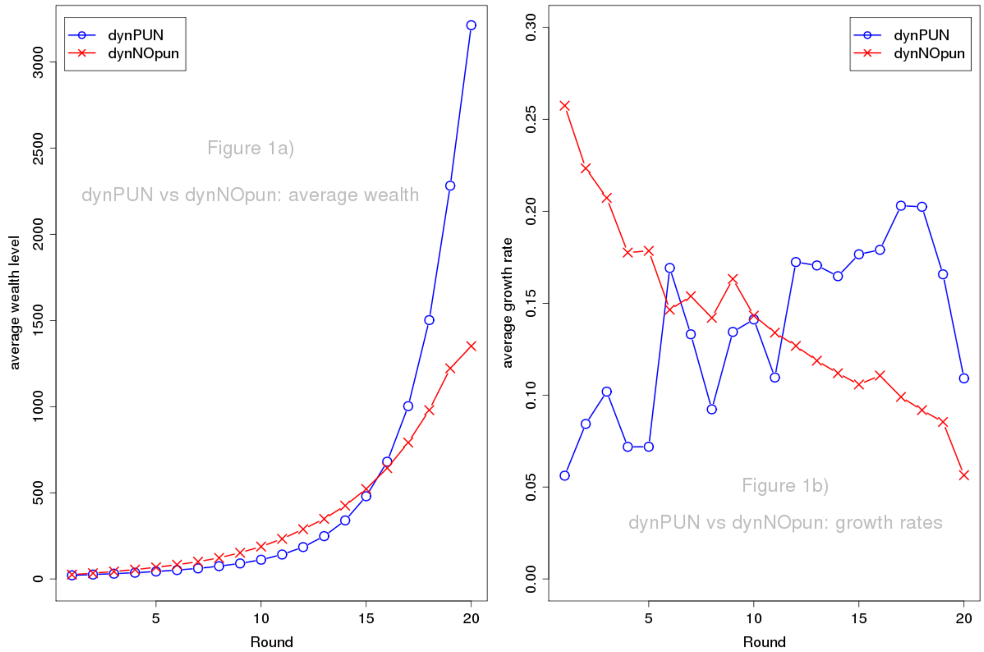

Figure 1: a) Average wealth levels from both treatments (left), and b) and average growth rates of wealth (right).

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 (p-values for quarters 2-4 are $p_{6-10} = 0.9314$, $p_{11-15} = 0.5457$, $p_{16-18} = 0.2973$, and $p_{19-20} = 0.8633$).

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 both the findings from previous research on peer-punishment in public-good games and our hypothesis **H2**–but in line with hypothesis **H3**–we do not find significant treatment differences in terms of contributions in any of the 20 rounds.[23]

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

[23]Apart from the final round ($p = 0.1217$), p-values are always above 0.25. Plotting average contributions, we obtain a graph that is very similar to Figure 1a; due to this similarity, we do not reproduce the graph here.

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*.[24] The treatment difference in relative 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* in the third period. Contrary to our hypothesis **H2**, the explanation seems to be driven by the number of groups attaining a comparatively high level of cooperation: whereas in *dynNOpun*, only two groups out of nine manage to reach an average level of relative contributions of at least 40%, the corresponding number for *dynPUN* is five out of nine.

Result 3. *Average 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.*

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 a fraction of the proceeds from the public good net of investments. 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 is lost, corroborating the argument leading to benchmark scenario **SCEN1**. 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.

[24] A spearman correlation test between the average relative contribution and time over the whole experiment has a p-value of 0.0612. The fractions of maximum-contributions tell a similar story: while the fraction increases in *dynPUN* from 2.8% in round 1 to roughly 10% in the final rounds, it plummets in *dynNOpun* from an initial 13.9% to 2.8% already in round 2, with only minor oscilations ever after.

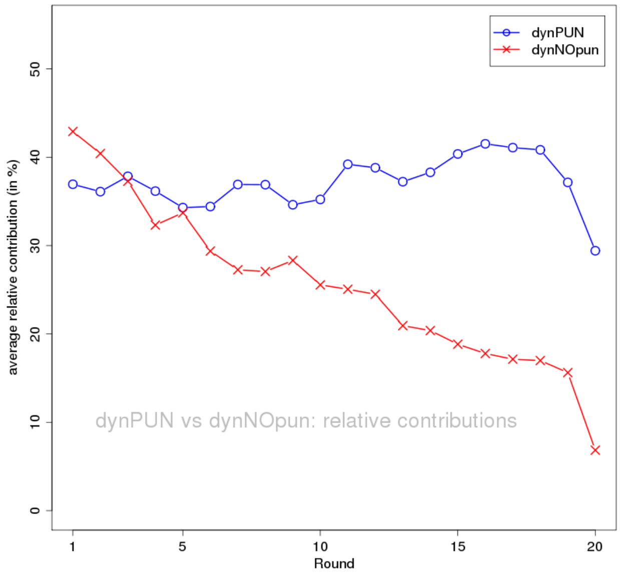

Figure 2: Treatment averages over contribution levels relative to current capabilities.

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.*

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 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 conducted by Nikiforakis and Normann (2008). Knowing that a comparison of these different data sets has to be judged cautiously, we compare them for an indication of the main trends.[25]

[25]The full comparison of punishment statistics from the four punishment treatments of Nikiforakis and Normann (2008) and our *dynPUN* treatment can be found in Table C.1 in Appendix C.

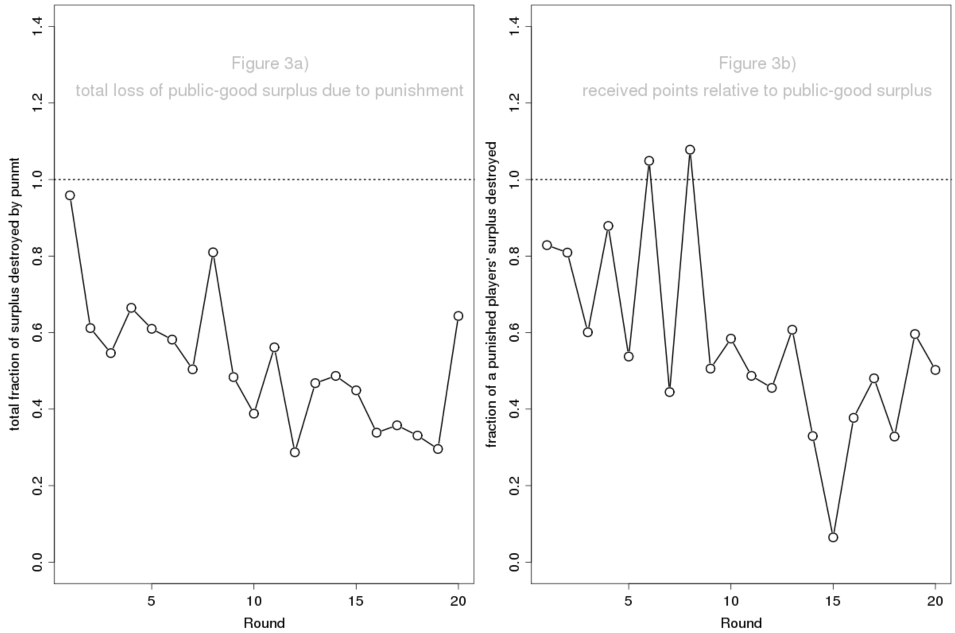

Figure 3: a) Average fraction of public-good surplus destroyed by punishment actions; b) Average fraction of punished players' surplus destroyed, (i.e., conditional on the players being punished).

Our first observation is that 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 (0.13 in *dynPUN* vs. $0.12, 0.19, 0.23$, and 0.33 in the 1:1 through 1:4 treatments in Nikiforakis and Normann, 2008), but more strikingly, that the number of punishment actions is substantially higher (0.72 vs. $0.45, 0.52, 0.45$, and 0.27). In light of the fact that there is no treatment difference with respect to the number of punishment assignments conditional on this number being positive, 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.

4.2 Individual reactions to others' behavior

How does the frequent but moderate punishment we observe affect contribution behavior? 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 (Wilcoxon tests: $p = 0.2031$ 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 ($p = 0.0152$). This effect can be produced in two different ways: (i) participants consciously may increase their relative contributions after being subject to sanctions, or (ii) they may have a tendency to keep the absolute contribution level 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 what other factors influence contribution decisions, we conduct the regression analysis reported in Table 1.

In our regression analysis, we regress a player's period-to-period change in relative contributions on a number of lagged variables that may be expected to influence the player's decision.[27] We use relative contributions to make decisions comparable between rounds (and consequently, endowments; we normalize most of the explanatory variables for the same reason). As potential explanatory variables we have three variables that measure deviations from the group average, each split up into a positive- and a negative-deviation variable, to account for the fact that reactions may differ depending on the player's position within the group. The first variable measures the deviation of the player's relative contribution from the group members' average contribution, to capture conditionally cooperative behavior. The second variable measures the player's wealth standing, to account for the player's 'historical' relative wealth level within society. Together with the variation coefficient of the group's current contribution capabilities, this variable is to give an indication of how the endogenously arising inequality influences behavior. The third deviation-from-average variable is meant to capture whether being

[26] The 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.

[27] Only 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 1: Results from a linear GLS regression of period-to-period changes in relative contributions, with individual random-effects and errors clustered by groups.[27]

Variable	***dynPUN***	***dynNOpun***
Positive deviation from the average relative contribution in $t-1$	-0.173 (0.110)	-0.181* (0.085)
Negative deviation from the average relative contribution in $t-1$	-0.004 (0.077)	0.216 (0.150)
Positive deviation from the average capability in $t-1$, normalized‡	-0.017 (0.015)	-0.018 (0.028)
Negative deviation from the average capability in $t-1$, normalized‡	0.081 (0.075)	0.184*** (0.045)
Positive deviation from the average surplus from the public good in $t-1$, normalized‡	0.009 (0.008)	0.004 (0.007)
Negative deviation from the average surplus from the public good in $t-1$, normalized‡	-0.060*** (0.016)	-0.070* (0.031)
Dummy: having been punished in $t-1$	0.001 (0.013)	
Received punishment as a fraction of the current wealth level in $t-1$	0.201** (0.061)	
Variation coefficient of the group's current contribution capabilities	-0.002 (0.022)	-0.086*** (0.023)
Period	-0.001 (0.001)	0.002 (0.002)
Logarithm of the group's average contribution capability	0.009* (0.004)	-0.006 (0.009)
Constant	-0.021 (0.017)	0.007 (0.024)
R^2	0.168	0.203

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

taken advantage of influences cooperation decisions. While all three variables are related, their combination allows for a more subtle picture of players' reaction to their peers' past contribution behavior. Additionally, we include 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 first model pertaining to the data from our *dynPUN* treatment, we add 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 to explore the effects from our non-parametric tests in further detail.

Treatment differences in high-contributor behavior. 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. This means 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 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).

Wealth effects and group heterogeneity. 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.[28] 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.

The effects of heterogeneity. In contrast, an increase in the gap between poor and rich leads to less cooperative behavior only in *dynNOpun*. 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*.[29] In the beginning, a higher level of heterogeneity 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 de Quervain et al. (2004). At the same time, the detrimental effect of heterogeneity in *dynNOpun* is in line with the results of

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

[29]Note that there is no treatment difference in terms of heterogeneity as measured by variation coefficients over the wealth levels within groups. Also, there is no clear time trend with respect to the variation coefficients.

[30]More 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.

earlier studies of endowment heterogeneity such as Anderson et. al (2008) or Cherry et al. (2005).

Reactions to punishment. Finally, in terms of punishment our regression analysis (cf. Table 1) 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 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.

This kind of dynamics, analysed in three recent studies (Gächter et al., 2009; Battaglini et al. 2010; and Cadigan et al., in press) gives rise to three critical issues: (i) punishment in early rounds may have a lasting detrimental effect on contribution capabilities (**Scen1**), (ii) potential punishers anticipating this may abstain from sanctioning, making the punishment institution pointless (**Scen2**), 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 (**Scen1**). At the same time, the likelihood of observing a cooperative group may increase

[31] In an unreported regression, we substitute three dummies corresponding to the potential 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.

as a result of the dynamics (**H2**). Summarizing our results, we find the dynamics by themselves do not solve the dilemma (**Result 3**) replicating the earlier findings of Gächter et al. and Cadigan et al.. At the same time, punishment – being particularly strong in early rounds – does have a detrimental effect on contribution capabilities (**Result 4**), as subjects do not abstain from sanctioning. The loss in contribution capabilities, however, 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 (**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* are higher, even though this difference is not large enough to yield a statistically significant difference (**Result 1**). Nonetheless, the evidence in favour of hypothesis **H3** is weak as it seems merely a question of time when the difference in contributions and, subsequently, wealth levels is strong enough to be statistically discernible.

Punished players' reactions are independent of the number of sanctioning players, only depending on their total size. Furthermore, 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.

The assignment of sanctions seems to have a second positive effect. It seems to prolong high-contributors' patience 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. This leads to 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. (2008) 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. On the one extreme, our benchmark scenario **Scen1** 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 **Scen2** 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, 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 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.

[32]As a matter of fact, there was a single assignment of 1 punishment point in period 16. In the final two periods, there where 2 (4) assignments, destroying 34 (50) out of 1216 (1259) points in period 19 (20; punisher costs included).

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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:

- 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

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

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 assignment costs**	**Tokens you assign to a group member**	**Your assignment costs**	**Tokens you assign to a group member**	**Your assignment 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 x 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:

Your **wealth after Stage 2** (Your wealth at the end of the round) = Your wealth account after Stage 1 – minus your costs of assignment for the tokens you assigned – minus reductions caused by the tokens assigned by other group members to you

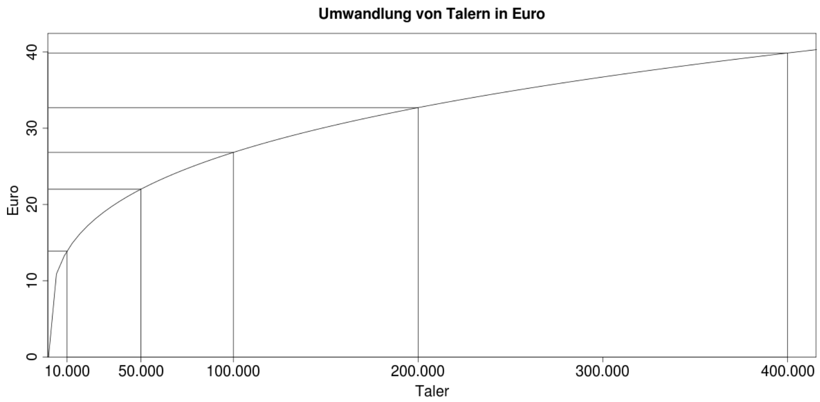
Information

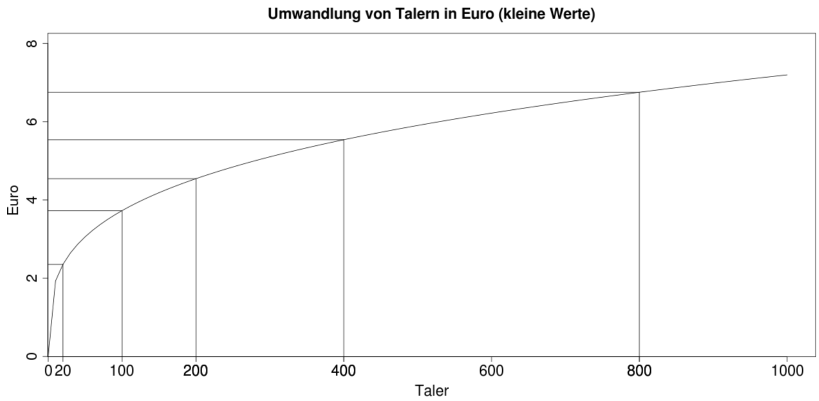
At the end of each round you will be informed about

- 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^t_{mm}, 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 $x^t_{mm} = E^t_{mm}, \forall t \leq T - t'$, where E^t_{mm} 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*

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

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

$$(1-\mu)(n-1) > (n-2)\beta_i - \alpha_i. \tag{3}$$

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. □

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 co-operators 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*

(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.

[33] Cf. Fehr and Schmidt (1999).

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

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

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

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

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

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

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

Reorganizing (5) yields

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

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,

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

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 $t, t \in \{1, ..., T\}$. □

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 Punishment statistics, additional regression results, overview figures for individual groups

Table C.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.

	Nikiforakis and Normann (2008)				Our data
Technology	1:1	1:2	1:3	1:4	$*1:2.8*$
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

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

Variable	***dynPUN***	***dynNOpun***
Positive deviation from the average relative contribution in $t-1$	-0.173 (0.120)	-0.168. (0.093)
Negative deviation from the average relative contribution in $t-1$	-0.007 (0.090)	0.242 (0.174)
Positive deviation from the average capability in $t-1$, normalized[‡]	-0.010 (0.018)	-0.025 (0.037)
Negative deviation from the average capability in $t-1$, normalized[‡]	0.086 (0.075)	0.180*** (0.045)
Positive deviation from the average surplus from the public good in $t-1$, normalized[‡]	0.009 (0.008)	0.003 (0.006)
Negative deviation from the average surplus from the public good in $t-1$, normalized[‡]	-0.058*** (0.017)	-0.071* (0.031)
Dummy: having been punished in $t-1$	0.001 (0.012)	
Received punishment as a fraction of the current wealth level in $t-1$	0.193** (0.066)	
Variation coefficient of the group's current contribution capabilities	0.139* (0.066)	-0.158 (0.116)
Period	0.001 (0.002)	0.001 (0.002)
Period $*$ Variation coefficient of the group's current contribution capabilities	-0.015* (0.006)	0.006 (0.009)
Logarithm of the group's average contribution capability	0.009* (0.005)	-0.008 (0.011)
Constant	-0.044* (0.022)	0.026 (0.037)
R^2	0.175	0.204

† 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.

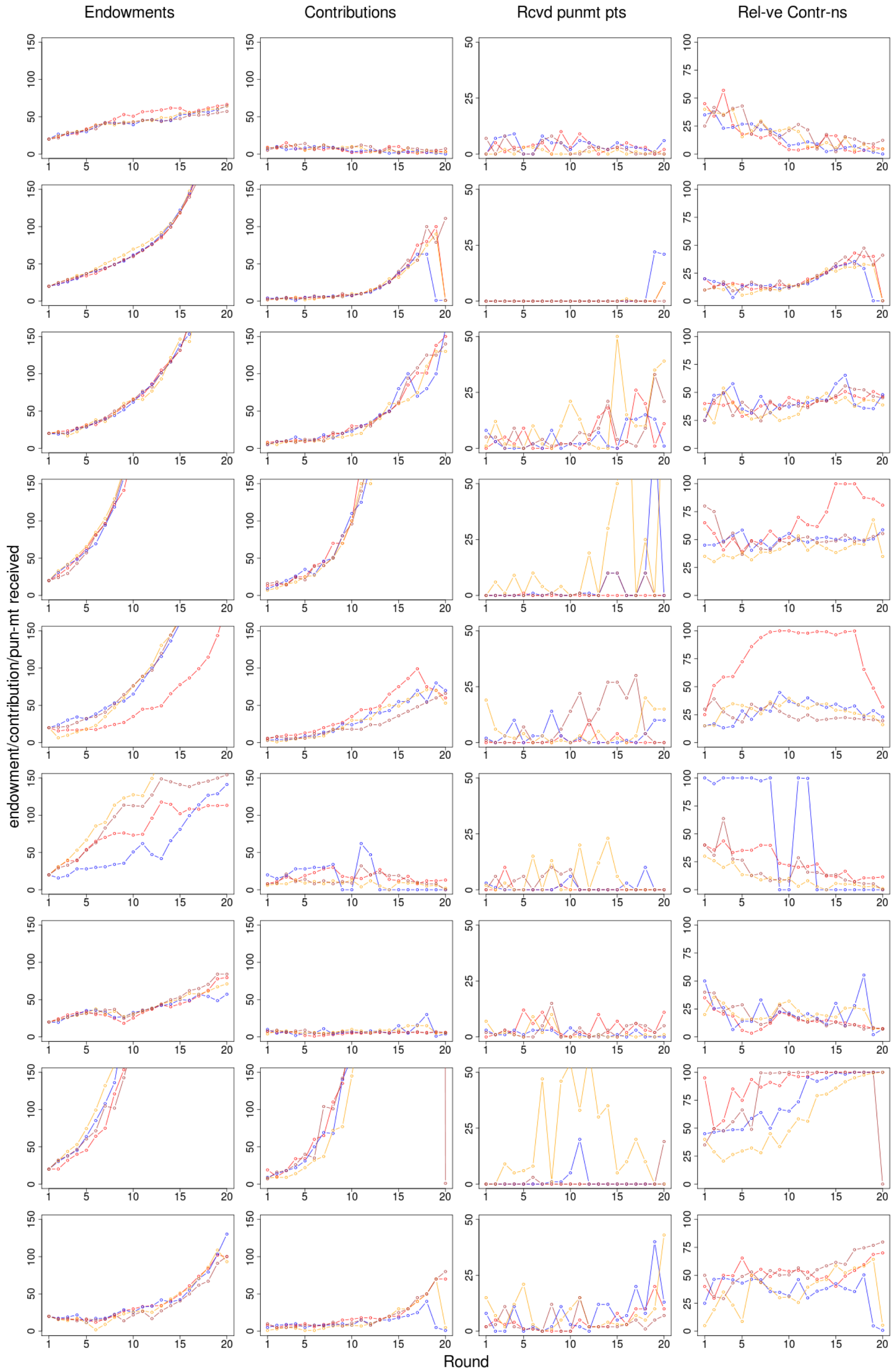


Figure C.1: Overview of the data from individual groups in the *dynPUN* treatment.

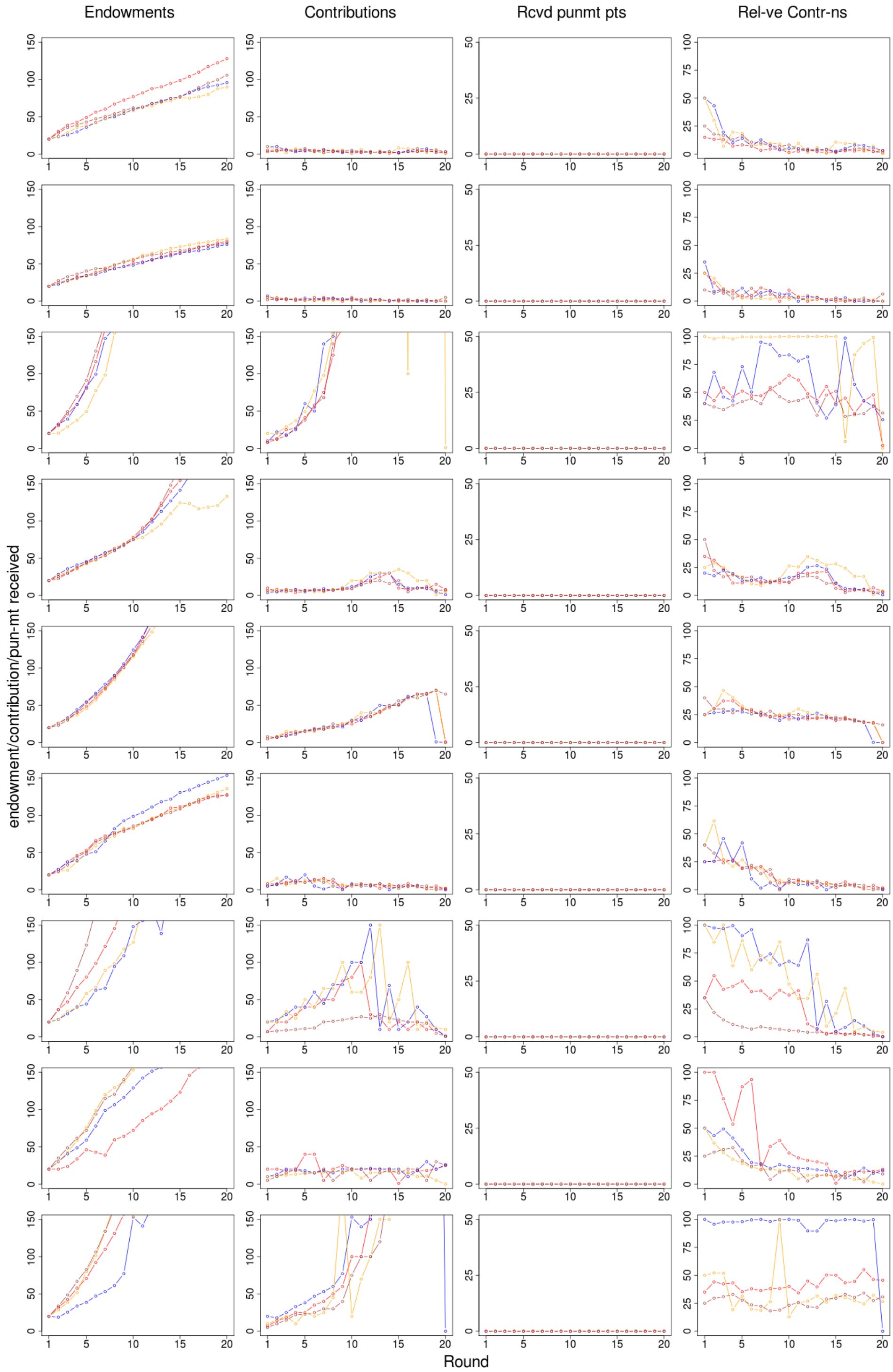


Figure C.2: Overview of the data from individual groups in the *dynNOpun* treatment. The third column is, of course, superfluous. We included it for easier comparison with the data from *dynPUN*.