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Sustaining cooperation in heterogeneous groups☆

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ABSTRACT

The public goods game has been studied extensively in the lab as the quintessential model of a social dilemma. Several mechanisms have been demonstrated to promote group cooperation in linear voluntary contribution experiments – such as communication, costly punishment, and centralized bonuses and fines. However, lab experiments have largely neglected a central obstacle to efficient public good provision: Individuals typically have different, private demands for consumption, hindering the ability of either a central authority or the group members themselves to calculate and enforce the optimal behavior. I adapt the standard public goods game to incorporate heterogeneous incentives and provide an assessment of each mechanism in this richer environment. I find that baseline cooperation is similar to that in the standard linear game. Sanctions are weak and generally ineffective. Communication, however, does promote cooperation, *especially* when subjects are given the opportunity to reveal their demand or demand is observable. Finally, a centralized fine/bonus scheme is most effective at increasing contributions, but low demanders must pay a fine in equilibrium.

1. Introduction

The public goods game has been studied extensively in the laboratory as the quintessential model of a social dilemma. The vast majority of these experiments consider homogeneous environments in which all participants share the same monetary incentives: typically, a dominant strategy to fully free-ride and a socially optimal strategy to fully contribute.[1] Contributions in these experiments typically begin midway between full free-riding and full contribution, but decline with repetition (Ledyard, 1995). Several mechanisms have been demonstrated to sustain group cooperation in this context, such as pre-play communication among participants (Isaac and Walker, 1988), peer monitoring and sanctioning (Fehr and Gächter, 2000), and centralized bonus/fine schemes (Falkinger et al., 2000).

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[1] Experiments that incorporate heterogeneous payoffs typically preserve the dominant strategy of full free-riding and the Pareto optimum of full contribution for all participants. Some exceptions are discussed in Section 1.1.

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Less is known, however, about how cooperation can be sustained in *heterogeneous* groups, in which agents have different, and often unobservable, demands. Heterogeneity poses a fundamental challenge to the efficient provision of public goods: While group members with common incentives are able to easily recognize, and potentially enforce, socially optimal behavior, agents in heterogeneous groups may not know the optimal behavior for each group member. The literatures in public finance and mechanism design suggest that the central obstacle to the efficient provision of public goods stems from individuals having private, unobservable demands for public good consumption (Samuelson, 1954; Green and Laffont, 1977). Given the challenge of efficiently providing public goods through taxation in this environment, it is particularly important to understand whether relatively simple mechanisms, such as communication and punishment, can enable heterogeneous groups to sustain optimal provision. It is therefore essential that lab experiments treat the efficient provision of public goods not only as an issue of overcoming egoistic behavior when all members of a group have common incentives and complete information, but also when social efficiency requires different contributions from different individuals and these incentives are private information.

Despite the challenge that private incentives pose to the efficient provision of public goods, there has been surprisingly little experimental work that incorporates heterogeneous dominant and socially optimal strategies into the standard voluntary contributions mechanism (VCM) game. In particular, we do not know how successful unrestricted communication, peer monitoring and sanctioning, or a Falkinger tax/subsidy mechanism for aligning the Nash outcome with the social optimum will be in such an environment. The aim of this experiment is therefore to test whether the most common mechanisms demonstrated to promote cooperation in homogeneous public goods experiments are also effective when social efficiency requires different contributions from different demand-types. In essence, do these mechanisms promote contributions in precisely the situation in which the public finance literature suggests efficient provision would otherwise be most difficult to achieve?

To address this question, a game was designed that incorporates heterogeneity into a simple VCM environment by assigning group members different private – but transparent – incentives. Participants were randomly assigned to be one of two known demand-types, where the types differ in both their payoff-maximizing strategy and their socially optimal strategy. Specifically, "Low Demanders" have a dominant strategy to fully free-ride, while their socially optimal strategy is to contribute half of their endowment to the public good. In contrast, "High Demanders" have a dominant strategy to contribute half of their endowment to the public good, while the socially optimal strategy requires them to contribute their full endowment. The payoff structures were carefully designed to ensure that the incentives for each demand-type were similar to, and just as clear as, those in the standard linear public goods game. First, just as in the linear game, neither the individually optimal contributions nor the socially optimal contributions depend on beliefs about the contributions of others – or, importantly in this case, on the composition of the group. Second, the payoffs for the two demand-types are identical under both the socially optimal and dominant strategy outcomes, so that inequality aversion should not influence behavior or differentially push the group toward the Nash or the optimal outcome. Finally, the Nash equilibrium payoff is 5/8ths of the optimal payoff, which is identical to that in many standard linear public goods games.

Two separate experiments were conducted, which differed in whether each individual's type was observable to their group members. In all treatments (described in detail below), participants interacted in a heterogeneous group of three people, which remained the same for the 10-period experiment. In the first experiment (*Private Incentives*), participants always learned the contribution of each group member – but *were not told* the group member's type or the composition of the group. In a follow-up experiment with complete information (*Observable Incentives*), participants knew the composition of their group and, at the end of each period, each individual's type was reported alongside their contribution. The first experiment captures the essence of the demand revelation problem, while the second allows us to assess whether the results are more broadly applicable to heterogeneous groups even with complete information.

In addition to the baseline game, three (Observable Incentives) to four (Private Incentives) additional treatments were conducted in each environment. The treatments incorporate the most common mechanisms that have been found to promote cooperation in the linear, homogeneous public goods experiment. In the *Sanctions* treatment, participants are able to pay to reduce the earnings of their group members, allowing us to address the question of whether peer monitoring and punishment will successfully promote cooperation when agents differ in their socially optimal contributions. Heterogeneous incentives may pose a particular challenge to the sanction mechanism when there is private information, since participants are unable to distinguish between types and, therefore, between cooperative and uncooperative behavior. For instance, if someone contributes half of his endowment in this experiment, his group members do not know whether he is a Low Demander making the socially optimal contribution or a High Demander maximizing his own payoffs. Thus, attempting to punish the latter comes at the risk of inadvertently punishing the former. The information obstacle is eliminated when incentives are observable, but the effective use of the sanction mechanism still requires group members to coordinate on and enforce a contribution norm in which the High Demanders contribute more.

In the communication mechanisms, participants are able to chat with their group members between periods. In the Private Incentives experiment, two separate communication treatments were conducted, which differed in whether (non-verifiable) revelation of one's type was expressly forbidden (*Restricted Communication*) or encouraged (*Unrestricted Communication*). The Restricted Communication treatment allows us to test the simple pro-social effect of communication in this environment, and serves as a replication of previous work on the effectiveness of communication in heterogeneous groups when agents cannot reveal private information (previously tested by Chan et al. (1999) and Isaac and Walker (1988) in heterogeneous environments that differ from the current paper, as discussed below). The Unrestricted Communication treatment, however,

allows for a novel test of demand revelation in the voluntary contributions game: *Will participants use the communication stage to directly lie to their group members about their payoff-type?* The comparison of the two treatments allows us to isolate the effect of participants being able to share, truthfully or untruthfully, their demands. In the experiment with Observable Incentives, there is no opportunity to hide or misrepresent one's type and thus only the Unrestricted Communication treatment was conducted.

In the *Falkinger* treatment, a centralized tax/subsidy scheme is implemented, in which above-average contributors are rewarded and below-average contributors are punished (Falkinger, 1996). This mechanism is budget-balanced and the parameters were set so as to align the Nash equilibrium and Pareto optimal contributions for both types. It thus provides a useful comparison mechanism to the communication and sanction mechanisms, which do not eliminate the monetary incentives to free-ride.[2] However, the mechanism cannot distinguish between the two payoff-types and requires a regular transfer of profits from the Low Demanders to the High Demanders in equilibrium.

The paper reports four main findings. First, the contributions in the baseline game closely conform to the pattern typically observed in the linear VCM game: Initial contributions are midway between Nash equilibrium and socially optimal levels and then decline significantly over the course the experiment. This suggests that, despite the novel design, participants approach the game similarly to the standard set-up. Second, the ability to sanction group members *does not* increase contributions above the baseline level, in either information environment. When incentives are observable, several groups successfully establish a norm at the social optimum, while, in other groups, High Demanders refuse to contribute above the group average and do not respond to punishment. When incentives are private, participants are unwilling to punish anyone except for unambiguous free-riders, and no group comes close to reaching the social optimum. Third, communication is successful at increasing cooperation – *especially* when types are observable *or* participants are permitted to non-credibly reveal their demand. Rather than underreporting their true demand and mistrusting their group members, nearly all participants truthfully reveal their type and report that they believe their group members' messages. Communication is particularly critical in this environment, as it enables participants to discuss and agree on the socially optimal vector of contributions. Fourth, the Falkinger tax/subsidy mechanism achieves the highest level of contributions across all treatments, but also the greatest payoff disparities between types, and contributions are not significantly higher than simply allowing participants unrestricted communication. The results of the experiment reported in this paper thus suggest that communication is *particularly effective and important* when agents have heterogeneous incentives and cooperation requires different contributions from different individuals. The poor performance of sanctions in this environment is broadly consistent with other work finding that punishment is weak and used unpredictably in situations where participants have difficulty converging on the efficient contribution norm, for instance due to heterogeneous earnings (Reuben and Riedl, 2013) or optimal contributions lying on the interior of the contribution space (Cason and Gangadharan, 2015). In contrast, the results illustrate that communication is likely to be particularly successful in this type of environment, as it enables participants to agree on the most socially efficient contribution strategy.

1.1. Related literature

This paper develops a novel experimental environment in which agents differ in their dominant strategy and socially optimal contributions, and these incentives may be unobservable to their group members. To the best of my knowledge, this is the first study to test the success of any of the common mechanisms for promoting cooperation in the standard VCM game – in particular, unrestricted communication, costly punishment, or the Falkinger mechanism implementing the optimal outcome – in this type of environment.[3] There are, however, several distinct strands of literature that are closely related.

First, several experiments incorporate *benefit* heterogeneity into the linear public goods game by altering the marginal return that participants receive from contribution. Free-riding is a dominant strategy in the linear game whenever the marginal per capita return (MPCR) from the public good is less than one. Thus, the change affects only the *magnitude* of the incentive to free-ride, without changing equilibrium behavior or the social optimum.[4] Despite this, participants are sensitive to these differences in MPCR: individuals with lower MPCR from the public good contribute significantly less in both homogeneous groups (Isaac et al., 1985) and heterogeneous groups (Fisher et al., 1995). The evidence suggests that heterogeneity in linear public goods returns suppresses contributions, especially when subjects are aware of the heterogeneity (Ledyard, 1995). Chan et al. (1999) employ a hyperbolic payoff function with heterogeneous parameters, such that group members may differ in their equilibrium strategies. They find that baseline contributions are close to the Nash predictions and overall find

[2] The experimental tests of the Falkinger mechanism reported in Falkinger et al. (2000) include a treatment in which participants are assigned heterogeneous non-linear preferences. However, the transfer tax/subsidy was not set to align the equilibrium with the optimal outcome. A goal in this paper is to test whether the mechanism can successfully implement the optimal outcome in a heterogeneous group.

[3] Beyond the context of induced value public goods games, where contributions benefit the immediate group members, other work has addressed the performance of specific mechanisms in promoting donations to real organizations or causes (e.g. Eckel and Grossman, 2008; Milinski et al., 2006; List and Lucking-Reiley, 2002; Karlan and List, 2007; DellaVigna et al., 2012; Linardi and McConnell, 2011). Participants in such studies will naturally have private, unobservable preferences for contribution.

[4] This is true as long as the MPCR remains between $1/n$ and 1 for all group members.

a positive effect of heterogeneity, a negative effect of incomplete information, and a positive interaction between them.[5] An overlapping subset of the literature investigates the effect of heterogeneity in endowments, largely reporting mixed results (see, for instance, Reuben and Riedl, 2013 for a recent summary).

The literature suggests that the primary challenge to cooperation presented by benefit or income heterogeneity is the introduction of conflicting contribution norms. While homogeneous payoffs align various norms – such as, contributing equally, contributing equal proportions of income, or equalizing final payoffs – these norms diverge when individuals have different payoffs (Neitzel and Sääksvuori, 2013; Bernard et al., 2014; Kingsley, 2016). Recent experimental work has investigated whether any of these potential norms would be enforced in heterogeneous groups, by incorporating punishment opportunities. This work has largely found that costly punishment increases contributions even in heterogeneous groups (Reuben and Riedl, 2013; Tan, 2008) – but that the effect is often weak and its success depends on the nature of the heterogeneity.[6]

This paper significantly differs from this work in that the primary goal is to study whether mechanisms such as punishment and communication will overcome the demand revelation problem, which occurs when agents differ in their demand for public good provision and these demands are private information. Studying whether groups can endogenously enforce the social optimum is particularly critical in this environment, where optimal provision generally cannot be implemented by a central authority. Consistent with this motivation, the current investigation diverges from the important work cited above in two key ways. First, group members have different interior optima, such that the social optimum requires different behavior from different demand-types and a cooperative contribution from one person could be a self-interested contribution from another group member.[7] In other words, social efficiency cannot be achieved by requiring all group members to contribute fully or by taxing everyone an equal amount. Rather than the challenge to cooperation coming in the form of unequal benefits or endowments, as in the previous work, this experiment is carefully designed to generate heterogeneous optima while holding constant the payoffs that different types receive from free-riding or cooperating. This allows us to isolate the influence of heterogeneous demands while avoiding the separate challenges that payoff inequality poses to cooperation, as found by the studies cited above. Second, individuals' incentives may be private information, which can impede the ability of group members or a central authority to enforce different contributions from different types.[8] To my knowledge, punishment has not been studied in groups where agents differ in their interior optima or when there exists incomplete information regarding group members' incentives.

The introduction of free form, pre-play communication also consistently increases contributions in the standard linear VCM game, frequently to full efficiency (Isaac and Walker, 1988; Sally, 1995; Bochet et al., 2006). Communication is effective at increasing participants' beliefs about what the others are likely to contribute and allows group members to coordinate on conditionally cooperative strategies (Brosig et al., 2003; Chaudhuri, 2011). Additionally, other work has found that free-form chat opportunities increase group identity and attachment (Chen and Li, 2009) and that allowing participants to only send numerical cheap talk messages, without the richer chat environment, does not generally promote cooperation (Bochet et al., 2006; Wilson and Sell, 1997). There has also been work investigating the effect of communication opportunities in heterogeneous groups (Design II in Isaac and Walker, 1988; Chan et al., 1999). However, unlike in the current Unrestricted Communication treatment, participants were typically forbidden from revealing private information to their group members during these communication periods (making these designs similar to the current Restricted Communication treatment).

Therefore, we know little about how communication would influence cooperation in heterogeneous environments when conversations are not censored. When types are unobservable and cannot be discussed, coordination on the social optimum

[5] Their design differs from the current paper in that agents do not have dominant strategies and the optimal allocation is not unique, so that group members must solve a coordination problem. Fellner et al. (2011) find that the type of information provided influences behavior in the linear game. In a public goods game with heterogeneous capacities (and no communication or punishment), they find that low types contribute more when they are aware of heterogeneity in the group, while high types contribute more when each group member's type is displayed alongside their contribution.

[6] For instance, both Reuben and Riedl (2009) and Kölle (2015) find that punishment has only a small effect on cooperation in groups where one individual receives a high return from public good provision, but Kölle (2015) finds a strong effect in groups where one individual is highly productive. The difference is that cooperation increases inequality in the former studies, whereas participants in the latter studies benefit equally from cooperation. The latter is thus closer to the current design, in which the marginal social benefit to cooperation is held constant across types and group composition. Both of these studies use linear public goods games with complete information. Kingsley (2016) considers a non-linear public goods game in which the social optimum requires group contributions to sum to a specific total (in any combination) and finds that punishment significantly increases contributions in groups with homogeneous endowments but not in groups with heterogeneous endowments. The situation differs in that optimal provision requires group members with different endowments to essentially coordinate on how to share the cost of provision.

[7] A recent experiment by Cason and Gangadharan (2015) suggests that, even in homogeneous groups, punishment may be less effective when agents have interior optima. They find that punishment eventually increases contributions in a non-linear public goods game, in which agents have (the same) interior dominant strategies, but the effect is weaker and emerges later than in the linear VCM.

[8] While the agents' payoffs are public information in the studies described above, other experiments have investigated the effectiveness of punishment when participants cannot perfectly monitor their group members' contributions (Ambrus and Greiner, 2012; Grechenig et al., 2010) or ability to have contributed (Bornstein and Weisel, 2010; Patel et al., 2010). These studies generally find that punishment is used less frequently, and contributions are lower, than when contribution behavior can be perfectly monitored. However, to the extent that the designs allow for a direct comparison between contributions in the presence and absence of a sanctioning mechanism, this work typically finds that punishment remains an effective tool for increasing contributions in these imperfect monitoring environments.

may be impeded, as it is unclear when someone deviates from the agreed upon contributions for each type.[9] When types *can* be discussed, and participants have the opportunity to mislead their group, High Demanders may find it in their best interest to misrepresent their type in order to give the appearance of cooperating, and keep conditionally cooperative group members contributing, while actually playing their dominant strategy. However, a variety of recent experimental work has shown that participants often truthfully report private information to group members against their own material interest.[10] When incentives are observable, participants do not face either of these hinderances. Thus, these experiments allow us to assess whether communication enables participants to coordinate and agree on a socially efficient outcome that requires group members to contribute according to their demands.

While less directly related to the present study, there is also a substantial body of experimental work on the design of mechanisms to reveal demand for public goods, going back to the work of Bohm (1972) and Smith (1979). Chen (2008) provides a comprehensive review of the experimental mechanism design literature. This work has largely focused on testing the effectiveness of mechanisms that induce truthful demand revelation in equilibrium and, from the perspective of the participants, typically abstracts away from both the social dilemma of public good provision and from framing one potential message as "true." In contrast, the current paper considers an environment in which participants can report to their group members (rather than a mechanism) within a free-form chat and are *not incentivized* to tell the truth. Additionally, both the truthfulness of different messages and the consequences of their behavior for the other participants are fully transparent.[11] One overarching finding in this literature is that, even when the mechanism generates a truth-telling dominant strategy, participants frequently do not truthfully reveal their preference parameters (Attiyeh et al., 2000; Kawagoe and Mori, 2001). However, they do tend to follow best response dynamics (Healy, 2006) and reach (other) Nash equilibria (Cason et al., 2006). The difficulty that participants have revealing their demand, even when facing a mechanism that induces truthful revelation in weakly dominant strategies, further reinforces the usefulness of testing simple solutions (such as communication and punishment), as possible alternatives to more complicated incentive-compatible mechanisms.

2. Experimental design

2.1. The baseline public goods game with private, unobservable incentives

This section first describes the payoffs and procedures of the Baseline public goods game with unobservable incentives, before turning to the mechanism treatments (Section 2.2) and discussing how the procedures differed in the Observable Incentives experiment (Section 2.3).

All participants played a 10-period public goods game and interacted using the experimental economics software z-Tree (Fischbacher, 2007). They were matched in the same group of three participants for the duration of the experiment and both the number of periods and the constant matching were common knowledge. In every period, each participant received an endowment of tokens and could choose how many tokens to contribute to a "group account" and how many to keep in one's "private account." Each participant then received a payoff in experimental "points" that depended on the number of tokens personally contributed, the number of tokens contributed by the other two group members, and the participant's payoff type: either a "High Demander" or a "Low Demander."[12] At the end of the experiment, the point totals were summed over all ten periods, converted to US dollars at the rate of 50 points = 1 USD, and added to a $5 show-up fee.

Each participant was assigned to be either a High Demander or a Low Demander for the duration of the experiment (although they first played both roles in a practice round, described in detail later). The existence of two different types and the payoffs of each were common knowledge and the participants were given paper instructions containing both payoff tables to refer to throughout the experiment. They did not, however, have complete information about the composition of their group in this experiment. Instead, they were told that there was *at least one* of each type in their group. Thus, discovering their own types did not give subjects any additional information about the composition of their group. In order to control the conditions that each group experienced, all always contained two High Demanders and one Low Demander.

The payoffs were constructed with several considerations in mind. Of primary importance was that the incentives for each type be both transparent and salient. Wherever possible, effort was made to keep the design in line with the substantial body of previous work on public goods games. However, one necessary difference comes from the fact that the standard

[9] For instance, in their analysis of communication transcripts, Brosig et al. (2003) find that participants regularly express a willingness to cooperate alongside a threat to stop cooperating if their group members do not also contribute.

[10] Although economic theory typically assumes that lying is costless and individuals will lie whenever it is in their interest to do so, several experiments document an aversion to lying in sender–receiver games (Gneezy, 2005; Lundquist et al., 2009), to the extent that some individuals will avoid lying even when doing so would be beneficial to both parties (Erat and Gneezy, 2012; Cappelen et al., 2013). Likewise, participants given the opportunity to communicate in bilateral bargaining games regularly reveal their private values and costs truthfully (e.g. Ellingsen et al., 2009).

[11] Exceptions include the test of the Falkinger mechanism reported in Falkinger et al. (2000) and Rondeau et al. (1999), who assign participants heterogeneous induced values for public good provision and study the extent to which their contributions reveal their demand in a one-shot provision point mechanism experiment. In the latter study, participants tend to *over-report*.

[12] These terms were not used in the experiment. Instead, the two types were referred to using neutral labels of "Y-Type" and "Z-Type." The more descriptive labels are used in the paper for clarity.

Own Contribution

Total Contributions of Other Two Group Members	0	1	2	3	4
0	20	25	30	25	20
1	30	35	40	35	30
2	40	45	50	45	40
3	50	55	60	55	50
4	60	65	70	65	60
5	70	75	80	75	70
6	80	85	90	85	80
7	90	95	100	95	90
8	100	105	110	105	100

Own Contribution

Total Contributions of Other Two Group Members	0	1	2	3	4
0	10	5	0	0	0
1	20	15	10	0	0
2	30	25	20	0	0
3	40	35	30	0	0
4	50	45	40	0	0
5	60	55	50	0	0
6	70	65	60	0	0
7	80	75	70	0	0
8	90	85	80	0	0

Fig. 1. The payoffs for a High Demander (left) and a Low Demander (right).

linear payoff function could not be used to generate interior equilibria or optima.[13] To avoid presenting the participants with more complicated payoff functions, payoff tables were generated, which showed the point payoffs from each possible combination of contributions.

The payoff tables given to the participants are shown in Fig. 1. The left table shows the point payoffs for a High Demander in each situation and the right table shows the payoffs for a Low Demander. Each column refers to the number of tokens that the individual himself contributes to the group account in the period, and the rows refer to the total number of tokens contributed by the two other group members. The endowment was restricted to 4 tokens to save participants from wading through massive tables that masked the true incentives of each type.[14] Note that each type has a dominant strategy, such that their best response does not depend on their beliefs about the composition of their group. Holding constant the contributions of the other group members, a High Demander's payoff is always highest when he contributes two tokens (as seen by looking from left to right in any given row) and a Low Demander's payoff is highest when he contributes zero tokens. Given that there are always two High Demanders and one Low Demander in a group, the Nash equilibrium prediction is that a total of 4 tokens will be contributed by the group.

Next, we turn to the socially optimal contribution for each of the two types. Again, the payoffs were constructed so that, for each type, the contribution that maximizes *social* payoffs does not depend on the composition of the group. For each extra token contributed by another group member, both types receive an additional payoff of 10 points (as seen by looking down each column of the tables in Fig. 1). Thus, the social benefit to cooperation does not depend on the number of High and Low Demanders in the group. As High Demanders increase their contributions from their dominant strategy of 2 tokens up to 4 tokens, it costs them 5 points per token. However, they are increasing *each* of their two group members' payoffs by 10 points per token. Therefore, it is socially optimal for the High Demanders to contribute all 4 tokens. Similarly, Low Demanders pay a cost of 5 points for each token that they contribute (up to 2 tokens), while increasing each of their two group members' payoffs by 10 points per token. Thus, the social optimum is for the two High Demanders to contribute 4 tokens each and the Low Demander to contribute 2 tokens, for a group total of 10 tokens.

Finally, the experiment was designed so that the payoff that each participant would receive if the group played according to the Nash prediction or according to the social optimum is the same for the two types. Under the Nash prediction, both the Low Demanders and the High Demanders receive 50 points per period. Under the optimal outcome, both the Low Demanders and the High Demanders receive 80 points per period. Thus, inequality aversion or fairness considerations should not affect contributions or differentially push the group toward the Nash outcome or the optimal outcome. Additionally, the Nash equilibrium payoff as 5/8 of the optimal payoff is comparable to that in many standard linear public goods games.[15]

The payoffs are also in line with previous experiments that used non-linear payoff functions. For instance, Keser (1996) uses a payoff function of the form: $A^*(\text{tokens in private account}) - B^*(\text{tokens in private account})^2 + C^*(\text{all tokens contributed to public account})$. This gives each subject a (possibly interior) dominant contribution. While Keser (1996) did not investigate heterogeneous groups, this payoff function would also give each individual a social payoff maximizing contribution that does not depend on group composition, provided the parameter C is identical for all group members. In fact, the payoffs presented in Fig. 1 were based on this payoff function, with several adaptations made in order to ensure the final payoff tables were as clear and salient for the participants as possible in the heterogeneous game.[16]

[13] In the standard linear public goods game, each player receives a payoff equal to his endowment minus his contribution plus a times total group contributions. Thus, both the Nash equilibrium and the social optimum are always corner solutions, which depend on the value of a and a times the number of players, respectively.

[14] The specific payoff functions used to generate the tables are, for High Demanders, $30 - 5|\text{Contribution} - 2| + 10(\text{Contribution of Others})$ and, for Low Demanders, $10 - 5(\text{Contribution}) + 10(\text{Contribution of Others})$ if Contribution < 3 and 0 otherwise. Only the tables were presented to participants.

[15] For instance, in a four person public goods game with marginal per capital return of 0.4 (as in Fehr and Gächter, 2000, among many others), we would find this same ratio of Nash payoffs to optimal payoffs.

[16] Specifically, the magnitudes were adjusted in order to make the incentives sharp and equalize the payoffs across the two types, the points were rounded to multiples of five in order to make the marginal benefits and costs easier to process and explain, and negative payoffs were zeroed out so that behavior would not be influenced by the possibility of losses. Researchers less concerned with keeping the ratio of Nash to Pareto Optimal payoffs equal to 5:8 may

The experiment depends critically on the subjects' understanding of each type's incentives. Therefore, prior to participating in the main experiment, subjects participated in a 10-period "practice" part to learn about the experiment, the software, and their incentives. The participants were told that all players would have the payoffs of Low Demanders for the first five periods. The participants were then rematched into new groups of three and told that all players were High Demanders for the final five periods. They thus gained experience in both roles and with the software prior to the main experiment.[17] Following the practice round, instructions were distributed for the experiment and participants were rematched into new groups. Instructions for both the practice part and for each of the five conditions of the main experiment are provided in the Appendix and each of the conditions is described in detail below.

Overall, 153 NYU students participated in this experiment. Ten sessions were conducted, with two sessions corresponding to each of the five treatment conditions. The first of the five treatments was the *Baseline* game described above and the additional treatments are described in the following section. Between nine and eleven independent groups of three participated in each treatment.[18] Average earnings were approximately $13 (plus a $5 show-up fee) and ranged between $7 and $18. Participants were typically in the lab for approximately 45 min.

2.2. The mechanisms

In addition to the Baseline treatment, four additional treatments were conducted. In each, one mechanism was added to the baseline game described above.

In the *Restricted Communication* and *Unrestricted Communication* treatments, subjects were given the opportunity to discuss the experiment with their group members. At the start of each period, a chat box appeared on the screen. They had one minute to talk about the experiment or other matters, but they could also exit the chat stage earlier if all three group members clicked an "End Chat" button on their screen. Everyone remained in the chatroom until all group members had hit "End Chat," so there was no risk of missing out on a conversation by pressing the button prematurely. The two conditions were identical except in the instructions. Participants in the Restricted Communication treatment were told that they were not allowed to reveal their payoff type, either directly or by indicating any quantitative or qualitative information from the payoff table associated with their type. Participants in the Unrestricted Communication treatment, on the other hand, were explicitly told that they were free to reveal their type and that they were free to be dishonest in doing so.[19] In both treatments, subjects were prohibited from making physical threats, discussing side payments, using offensive language, or from revealing their names, appearance, or seat locations to their group members.

In the *Sanctions* treatment, participants could pay to reduce their group members' earnings. To keep the information identical across treatments, participants in all treatments were shown each group member's personal contribution immediately following the contribution stage. Each group member's contribution was displayed in a separate box on the screen and the order in which the boxes appeared was randomized each period. Participants in the Sanction condition were able to type below each box how many points they would like to pay to reduce that individual's earnings. The individual then had his earnings reduced by *three times* the amount paid, a rate previously found to be highly effective in raising and sustaining contributions (Nikiforakis and Normann, 2008).[20]

The final treatment, *Falkinger*, introduced a centralized mechanism for fining and rewarding participants based on how their contribution differed from those of their group members. The mechanism was devised by Falkinger (1996) as a means of aligning individual and group incentives and later found to be effective in promoting contributions in the lab (Falkinger et al., 2000). For the experiment reported in this paper, the following term was added to each individual's payoff: $6 * (\text{Own Contribution} - \text{Average Contributions of Two Other Group Members})$. Thus, individuals with above-average contributions earn a subsidy, individuals with below-average contributions are taxed, and these payoff transfers are budget balanced. Participants in this condition were provided with the updated payoff table in Fig. 2, which indicates what their payoffs would be in each case with the tax/subsidy included. The unique Nash equilibrium in this game is for High

also wish to add an additional constant to all payoffs to avoid zeros. Other public goods experiments with homogeneous interior optima include Sefton and Steinberg (1996), Bracha et al. (2011), and Kingsley and Liu (2014).

[17] There is evidence that participants understood the incentives. Prior to the practice rounds, participants answered quiz questions in which they had to identify the contribution level that maximized their own payoff and the group's payoffs in the homogeneous groups. Most participants answered at least 3 out of 4 of these questions correctly on their first attempt, even before the practice rounds. Further, during the main experiment, contributions lie within the expected range (between 0 and 2 for Low Demanders and between 2 and 4 for High Demanders) in approximately 98.5% of observations. Finally, the finding that the pattern of contributions in the baseline treatment closely matches the standard pattern in the linear game provides further reassurance that the participants understood their incentives.

[18] Specifically, there were 10 groups in the Baseline and Sanctions treatments, 9 in the Falkinger treatment, and 11 in each of the communication treatments.

[19] This statement was included in the instructions to emphasize the difference between the treatments and thus allow for the assessment of whether (truthful or untruthful) revelations of type could promote cooperation. The experiment therefore does not address the extent to which participants would recognize the benefit of discussing types and initiate these discussions entirely unprompted.

[20] It is worth noting that individuals earn 10 (12) more points in this (Nikiforakis and Normann's) set-up from fully free-riding than fully cooperating and thus four punishment points are required to erase the gain from free-riding in both set-ups.

Own Contribution

Total Contributions of Other Two Group Members

	0	1	2	3	4
0	20	31	42	43	44
1	27	38	49	50	51
2	34	45	56	57	58
3	41	52	63	64	65
4	48	59	70	71	72
5	55	66	77	78	79
6	62	73	84	85	86
7	69	80	91	92	93
8	76	87	98	99	100

Own Contribution

Total Contributions of Other Two Group Members

	0	1	2	3	4
0	10	11	12	18	24
1	17	18	19	15	21
2	24	25	26	12	18
3	31	32	33	9	15
4	38	39	40	6	12
5	45	46	47	3	9
6	52	53	54	0	6
7	59	60	61	-3	3
8	66	67	68	-6	0

Fig. 2. The Falkinger condition payoffs for a High Demander (left) and a Low Demander (right).

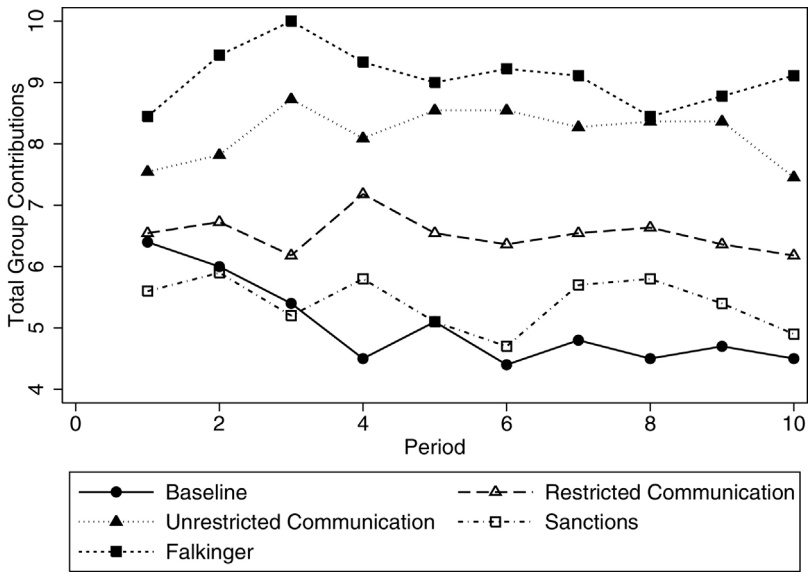

Fig. 3. Total group contributions under each condition (Private Incentives). *Note*: The total contributions for the group is 4 under the Nash equilibrium and 10 under the Pareto optimum.

Demanders to contribute 4 and Low Demanders to contribute 2 and this result does not depend on the group composition.[21] The Nash prediction is thus identical to the social optimum.

2.3. Observable Incentives experiment

To test whether the effectiveness of these mechanisms is similar in heterogeneous groups when participants have *complete information*, a follow-up experiment was conducted. Conditions were nearly identical in the follow-up experiment, except that each individual's payoff type was observable to the group members. At the start of the experiment, participants learned both their own type and the composition of their group. Consistent with the previous experiment, participants learned the contributions of each group member at the end of each period. In this experiment, however, each individual's type was reported alongside their contributions. While this environment less directly captures the demand revelation obstacle to efficient public good provision, it is consistent with a situation in which the group members themselves have superior information about each group member's incentives.

In addition to the Baseline, three mechanism treatments were conducted in this experiment: Unrestricted Communication, Sanctions, and Falkinger. Each participant's type was always observable to their group members, and thus there was no need for two separate communication treatments in this experiment. Instead, each group member's type always appeared

[21] To see this, note that the High Demanders always have a marginal benefit of 6 for the first two tokens they contribute and 1 for the third and fourth tokens they contribute. Thus, High Demanders have a dominant strategy to contribute 4, regardless of the group composition. The Low Demanders do not have a dominant strategy, but their best response to any reasonable beliefs about the contributions of others, regardless of group composition, is to contribute 2. They would only prefer to deviate from 2 if the other two group members were contributing less than 2 in total, an outcome that would only occur if both group members were playing strictly dominated strategies. Thus, regardless of the group composition, there exists a unique Nash equilibrium in which High Demanders contribute 4 and Low Demanders contribute 2.

Table 1
The effect of mechanism on contributions (Private Incentives).

	(1) Total contributions	(2) Total contributions	(3) Low contributions	(4) High contributions
Restricted Communication	1.497**	1.383**	0.658**	0.420*
	(0.678)	(0.651)	(0.302)	(0.240)
Unrestricted Communication	3.143***	2.823***	0.713**	1.215***
	(0.678)	(0.658)	(0.302)	(0.240)
Sanctions	0.380	0.499	0.170	0.105
	(0.694)	(0.664)	(0.310)	(0.245)
Falkinger	4.059***	3.792***	1.051***	1.504***
	(0.713)	(0.688)	(0.318)	(0.252)
Females		−0.646**		
		(0.261)		
Economists		−0.106		
		(0.236)		
Constant	5.030***	6.717***	0.760***	2.135***
	(0.491)	(0.842)	(0.219)	(0.174)
Estimate of Unrestricted – Restricted Communication	1.645**	1.44**	0.054	0.795***
	(0.662)	(0.642)	(0.295)	(0.234)
Estimate of Falkinger – Unrestricted Communication	0.916	0.969	0.338	0.289
	(0.698)	(0.665)	(0.311)	(0.246)
Observations	51	51	51	51
Adjusted R^2	0.476	0.525	0.178	0.525

Standard errors in parentheses. OLS estimates reported. The dependent variable is the group's total contribution (Columns 1 and 2) or individual-level contribution (Columns 3 and 4). Economists refers to the number of group members with economics training.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

beside their message in the chat box. Overall, 120 Middlebury College students participated in the Observable Incentives experiment, with nine to eleven groups of three participating in each condition. As in the private information experiment, two sessions were conducted for each of the four conditions, with 12–18 participants in each session. Earnings averaged $13.84 (plus a $5 show-up fee) and participants were typically in the lab for approximately 45 min.

3. Baseline results and comparisons

In this section, we examine the contributions in the Baseline condition with private (Section 3.1) and observable (Section 3.2) incentives and consider the relative effectiveness of the mechanisms in both environments. The following section further analyzes behavior under each of the mechanisms.

3.1. Outcomes with private incentives

In the linear VCM game, the oft-replicated finding is that contributions in the first period are 40–60% of the way between Nash and optimal levels, but decline quickly over time (for instance, Ledyard, 1995). Similarly, total group contributions in the Baseline treatment average 6.4 in the first period: exactly 40% of the way between the Nash outcome of 4 and the social optimum of 10. The group contributions decline steadily over the ten periods, ending at 8.3%.[22] Thus, despite the novel experimental design, the pattern of cooperation in the Baseline treatment is very much in line with the standard findings in the more straight-forward game.

The average contributions over time in the Baseline treatment and each of the four mechanisms are shown in Fig. 3. Under no mechanism do the contributions decline (or increase) significantly over time, as they do in the Baseline.[23] Furthermore, a visual inspection of Fig. 3 suggests that the level at which contributions are sustained differs substantially across mechanisms. This conclusion is supported by the regression estimates reported in Table 1. For this analysis, we treat each group of three participants making contributions over all 10 periods as one observation. The dependent variable in the first two models (columns 1 and 2) is thus the total contributions made by the three group members, averaged over all 10 periods. The Baseline is the reference group and an indicator variable is included for each of the other mechanisms.

[22] The Spearman correlation between contributions and period is $\rho = -0.397$ and is significantly less than zero at all reasonable significance levels, taking the group-period as the unit of observation.
[23] The Spearman correlations between contributions and period for each of the other mechanisms are: Sanctions: $\rho = -0.074$ and $p = 0.47$; Restricted Communication: $\rho = -0.07$ and $p = 0.47$; Unrestricted Communication: $\rho = 0.034$ and $p = 0.72$; Falkinger: $\rho = -0.069$ and $p = 0.52$.

The first column of Table 1 indicates that the only mechanism that does not significantly increase contributions above the Baseline is Sanctions. The ineffectiveness of the sanctioning mechanism in this context is explored in Section 4. Both communication mechanisms increase cooperation above the Baseline, and contributions are significantly higher under the Unrestricted Communication treatment, when participants could share their demand-type, than the Restricted Communication treatment, when they could not.[24] Finally, we see that the contributions are highest under the Falkinger mechanism, although the coefficient is not significantly higher than under the Unrestricted Communication mechanism ($p = 0.2$). The second column reports the same regression model with controls for the number of females in the group and the number of group members who have taken economics courses and shows no difference in any of the significance results.[25]

The third and fourth columns of Table 1 consider the average individual contributions separately for each type. First, we note the difference in average contributions between the types in the Baseline condition (given by the constants in columns 3 and 4). High Demanders do contribute more tokens than Low Demanders (2.14 vs. 0.76, $Z = 3.8$, $p < 0.01$). However, when we consider each type's contribution as a percentage of the way from their self-interested contribution (2 for High Demanders and 0 for Low Demanders) to their socially optimal contribution (4 for High Demanders and 2 for Low Demanders), we see that Low Demanders cooperate far more, with Low Demanders contributing 38% of the optimum and High Demanders contributing less than 7% ($Z = 2.47$, $p = 0.014$).

With respect to the effect of the mechanisms on each type's contributions, the results are consistent with the overall group contributions: Both communication treatments and the Falkinger mechanism have a significant positive effect on the contributions of each type, while the Sanctions mechanism does not increase contributions for either type. Notably, the difference between Unrestricted and Restricted Communication is fully driven by the High Demanders. Relative to the Restricted Communication treatment, the ability to reveal one's type strongly increases contributions of High Demanders (who otherwise could hide as Low Demanders), but has no significant effect for Low Demanders (who would not be expected to contribute more if their type were revealed). In fact, Unrestricted Communication and Falkinger are the only conditions in which High Demanders do not cooperate *significantly less* than Low Demanders (as a percent of the distance from their dominant contribution to socially optimal contribution).[26] We further examine the outcomes under each mechanism in Section 4.

3.2. Outcomes with Observable Incentives

We next consider the Baseline and overall results in the Observable Incentives experiment, where the findings are broadly consistent with the Private Incentives experiment. Fig. 4 presents the total group contributions over time under each mechanism. We again find that the Baseline results conform to the pattern in the standard, linear public good experiment: Contributions start 55% of the way between the Nash and the social optimum and decline significantly over time.[27] Turning to the success of each of the three mechanisms at promoting cooperation in this environment, we observe that the results largely align with the Private Incentive experiment. Both the Falkinger and Unrestricted Communication mechanisms are highly – and similarly – successful at promoting cooperation, while the total contributions under the Sanctions mechanism are only slightly above the Baseline level.

The first two columns of Table 2 confirm these results: the Falkinger and Unrestricted Communication mechanisms both increase total group contributions by 2.5 tokens beyond the Baseline, while the contributions are only 0.5 tokens above the Baseline in Sanctions, an effect that does not reach statistical significance ($p = 0.29$ with the controls from column 2). The final two columns in Table 2 separately estimate the effect of each mechanism on the contributions of Low Demanders and High Demanders. Again, we find that the effect of the Falkinger and Unrestricted Communication mechanisms are similar in magnitude, increasing the contributions of Low Demanders by over one token and the contributions of High Demanders by approximately three-quarters of a token. The Sanction mechanism, in contrast, only significantly increases the contributions of Low Demanders and has no effect on the contributions of High Demanders. From these final two columns, we also note that the Baseline gap in cooperation between the Low Demanders and the High Demanders, which was observed in the previous experiment, closes when types are observable and High Demanders can no longer "hide." While Low Demanders' Baseline cooperation (40%) is similar to the Private Incentives experiment, High Demanders also cooperate (52%) in this environment and the difference between the types is not statistically significant ($Z = 0.885$, $p = 0.376$).[28]

[24] Comparing the coefficients on Restricted and Unrestricted Communication indicates that 1.65 more tokens are contributed in the Unrestricted condition than in the Restricted condition. The coefficients are significantly different at the $p = 0.02$ level.

[25] In addition, these significant results hold in every period from the fourth period on, and there is no difference in significance for any of the results if session-level clusters are included.

[26] Comparing the cooperation percentage across High and Low Demanders, we find significant differences in both the Restricted Communication treatment ($Z = 1.91$, $p = 0.057$) and the Sanction treatment ($Z = 2.98$, $p < 0.01$) in addition to the Baseline treatment reported above. In all tests, the group is taken as the unit of observation.

[27] $\rho = -0.20$ and $p = 0.06$.

[28] While they consider a very different environment, this result is broadly consistent with the finding of Fellner et al. (2011) that high types contribute more when each person's marginal productivity is displayed alongside their contribution.

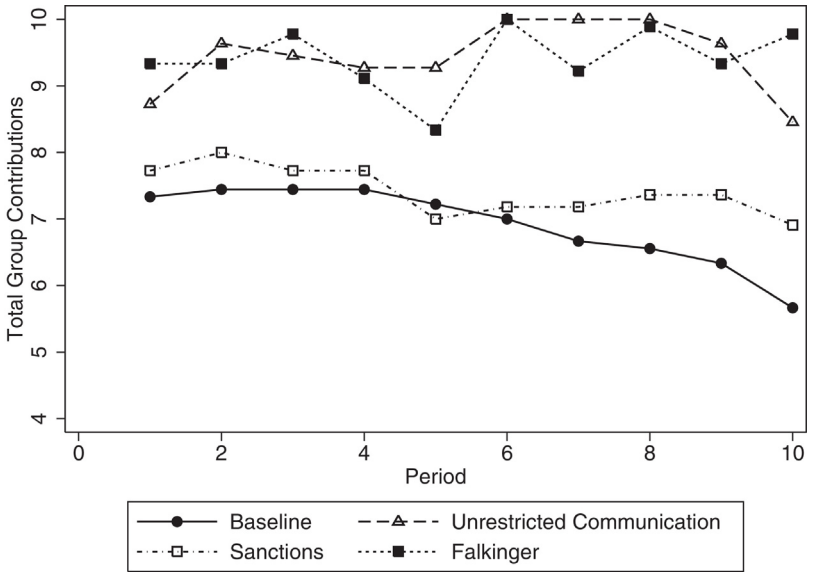

Fig. 4. Total group contributions under each condition (Observable Incentives). *Note:* The total contributions for the group is 4 under the Nash equilibrium and 10 under the Pareto optimum.

Table 2
The effect of mechanism on contributions (Observable Incentives).

	(1) Total contributions	(2) Total contributions	(3) Low contributions	(4) High contributions
Unrestricted Communication	2.534***	2.713***	1.073***	0.731***
	(0.705)	(0.711)	(0.297)	(0.265)
Sanctions	0.507	0.782	0.818***	−0.156
	(0.705)	(0.725)	(0.297)	(0.265)
Falkinger	2.500***	2.566**	1.011***	0.744**
	(0.739)	(0.943)	(0.311)	(0.277)
Females		0.269		
		(0.378)		
Economists		0.528		
		(0.359)		
Constant	6.911***	5.262***	0.800***	3.056***
	(0.523)	(1.227)	(0.220)	(0.196)
Estimate of Falkinger – Unrestricted Communication	−0.034	−0.147	−0.061	0.014
	(0.705)	(0.939)	(0.297)	(0.265)
Estimate of Unrestricted Communication – Sanctions	2.027***	1.931***	0.255	0.886***
	(0.668)	(0.668)	(0.281)	(0.251)
Estimate of Falkinger – Sanctions	1.993***	1.785*	0.192	0.900***
	(0.705)	(0.958)	(0.297)	(0.264)
Observations	40	40	40	40
Adjusted R^2	0.315	0.322	0.247	0.302

Standard errors in parentheses. OLS estimates reported. The dependent variable is the group's total contribution (Columns 1 and 2) or individual-level contribution (Columns 3 and 4). Economists refers to the number of group members with economics training.

* $p < 0.10$
** $p < 0.05$
*** $p < 0.01$

4. Mechanism results

4.1. Peer Monitoring and Sanctions

We next turn to the question of why the sanctioning mechanism fails to promote cooperation in this environment. There are two commonly observed reasons for the failure of punishment to substantially increase contributions relative to the baseline: It is underused or used inconsistently as a means of punishing low contributors (Nikiforakis and Normann, 2008; Reuben and Riedl, 2009) or it is used anti-socially, such that cooperators are punished rather than defectors (Herrmann et al., 2008).

Table 3
Sanction summary statistics by contribution and demand-type (Private Incentives).

Contribution	Observations	Percent punished	Expected reductions	Reductions given
0	55	56.36	4.97	0.60
1	5	0.00	0.00	0.00
2	206	8.74	0.41	1.18
3	12	8.33	0.25	1.00
4	22	0.00	0.00	3.27
Overall	300	17.67	1.2	1.2
Low's Contribution				
0	51	52.94	4.76	0.647
1	5	0.00	0.00	0.00
2	44	2.27	0.136	0.545
Overall	100	28.00	2.49	0.57
High's Contribution				
0	4	100.00	7.5	0.00
1	0	–	–	–
2	162	10.49	0.48	1.35
3	12	8.33	0.25	1.00
4	22	0.00	0.00	3.27
Overall	200	11.00	0.555	1.51

The table reports the punishment outcomes following each contribution level for all group members (top), Low Demanders (middle) and High Demanders (bottom). The columns indicate the frequency that the contribution was observed, the percentage of observations in which the individual making the contribution had their earnings reduced, the average reduction received, and the average reduction individuals making this contribution took from others.

We begin with the Private Incentive experiment, where the sanctioning mechanism is ineffective at generating the socially optimal provision in *any* of the 10 independent groups. The ineffectiveness of the sanctioning mechanism in this environment appears to be due to its underuse, particularly on low-contributing High Demanders. The sanctioning outcomes for High and Low Demanders making each possible contribution are summarized in Table 3. The table demonstrates that contributing *nothing* was the only behavior that reliably earned a participant a payoff reduction in this experiment. Participants who contributed zero tokens had their payoff reduced more than half of the time. Those who contributed their entire endowment were never punished, suggesting that anti-social punishment was not a consideration in this experiment – although full contribution was rare. Participants contributing two tokens were a mix of high-contributing Low Demanders and low-contributing High Demanders and this contribution level was rarely punished, presumably due to the ambiguity of group member's types. As a result, the Low Demanders incur most of the punishment. Although there are twice as many High Demanders as Low, the Low Demanders receive approximately 70% of all reductions and the average per-period payoff reduction for a Low Demander (2.49) is nearly five times that for a High Demander (0.55).[29]

Although participants who contributed nothing were likely to be punished, their expected reduction was only 4.97 points. Since Low Demanders faced a cost of 10 points if they increased their contribution from 0 to 2 tokens, this level of punishment would be insufficient to change the incentives of the Low Demanders and thus it is unsurprising that even the Low Demanders do not contribute significantly more under the sanction mechanism.[30] Thus, it appears that sanctions are unsuccessful at promoting cooperation in the Private Incentives experiment due to the fact that they were only levied at unambiguous free-riders and, even then, the level of reduction was not enough to incentivize cooperation. In addition to the weak financial motive, Low Demanders also lacked a reciprocal motive to increase their contributions, as High Demanders played their dominant strategy in the vast majority of observations (81%) and went largely unpunished.

The natural next question is whether sanctions could be used to successfully enforce the socially optimal outcome if High Demanders' free-riding could also be identified. This question is addressed in the Observable Incentives experiment. When participants had complete information about demand-types, punishment was directed at free-riders of both types and several groups were able to successfully sustain the social optimum. However, in other groups, the High Demanders were unwilling to contribute above the group average and did not respond to punishment. Thus, complete information may not be sufficient to guarantee the success of sanctions in this environment.

[29] It is interesting to note that High Demanders who contribute 2 do get punished at a higher rate than Low Demanders making the same contribution. In most of these cases, both High Demanders contributed 2 and both were punished by the Low Demander. However, it generally paid for High Demanders to hide among Low Demanders by contributing 2: High Demanders who contributed 2 earned significantly more than High Demanders who contributed more than 2 in this environment ($p < 0.05$, clustering at the either the individual or group level). In contrast, Low Demanders who were similarly uncooperative (contributed 0) did not earn significantly more than those who contributed ($p = 0.43$).

[30] A regression of Low Demanders' contributions on their previous contribution and previous reductions indicate that Low Demanders respond significantly to being punished ($p < 0.01$, with standard errors clustered at the individual or group level), but the magnitude of the response is weak, corresponding to an increase of 0.05 tokens for each reduction point received. A similar assessment for High Demanders indicates that there is no response to being fined.

Table 4
Sanction summary statistics by contribution and demand-type (Observable Incentives).

Contribution	Observations	Percent punished	Expected reductions	Reductions given
0	23	43.48	6.78 (5.68)	10.57 (1.74)
1	4	75.00	8.25	3.75
2	193	32.64	5.38 (4.58)	4.01
3	14	7.14	0.21	6.21
4	96	4.17 (4.60)	0.31 (0.35)	1.47
Overall	330	24.55	3.82 (3.25)	3.82 (3.25)
Low's Contribution				
0	21	38.00	6.29 (4.94)	11.57 (1.94)
1	2	50.00	6.00	3.00
2	86	15.11	1.57	5.02
4	1	100.00	6.00	0.00
Overall	110	28.00	2.59 (2.39)	6.19 (4.60)
High's Contribution				
0	2	100.00	12.00	0.00
1	2	100.00	10.5	4.5
2	107	46.73	8.44 (6.99)	3.20
3	14	7.14	0.21	6.21
4	95	3.16 (3.48)	0.25 (0.28)	1.48
Overall	220	26.36	4.43 (3.68)	2.63

The table reports the punishment outcomes following each contribution level for all group members (top), Low Demanders (middle) and High Demanders (bottom). The columns indicate the frequency that the contribution was observed, the percentage of observations in which the individual making the contribution had their earnings reduced, the average reduction received, and the average reduction individuals making this contribution took from others. Numbers in parentheses show results excluding the final period in cases where the magnitudes differ by more than 10%.

Table 4 displays the punishment outcomes in the Observable Incentives experiment. When types can be observed, the sanctioning mechanism is used relatively equally against free-riders of both types. Low Demanders who contribute 0 and High Demanders who contribute 2 are punished with similar frequency (38% vs. 46.7%) and intensity (6.29 points vs. 6.99 points).[31] For several groups, the complete information about group members' types was sufficient to enforce the optimal group outcome. Four out of 11 groups punished any deviation from full cooperation and sustained group contributions of 9.5 or higher for the duration of the experiment. The percentage of groups successfully using punishment to enforce full cooperation matches the findings of Reuben and Riedl (2013), who report four out of 10 or 11 groups in each of their heterogeneity treatments establish and enforce a contribution norm of full cooperation.[32] In the four groups that achieved the socially optimal contribution, every single group member "strongly disagreed" with the statement that all group members should contribute the same number of tokens in a post-experiment questionnaire, which was not true of any of the other groups.

In the other groups, however, complete information about type was insufficient to facilitate the effective use of punishment in sustaining group cooperation. In particular, many High Demanders seemed unwilling to contribute above 2 and, in nearly half of observations (48.6%), High Demanders neglected to contribute more than the group's Low Demander. High Demanders who played their dominant strategy in these groups, and were punished for it, were significantly more likely to respond by punishing their group members in the subsequent period (42.5%) than they were to increase their own contributions (22.5%). Nearly a third of the High Demanders' punishments were directed at high contributing High or Low Demanders. Furthermore, High Demanders playing their dominant strategy did not significantly increase their contribution in response to previous period punishments – although those who were punished after contributing 3 or 4 do significantly *decrease* their contribution in the next period, demonstrating that anti-social punishment had a clear detrimental effect on group cooperation.[33] In contrast, Low Demanders exhibited high levels of cooperation from the first period (86%) and never punished anti-socially.

Thus, while complete information about group member types facilitated the punishment of free-riding High Demanders, and enabled nearly 40% of groups to enforce full cooperation, the magnitude of punishments was weak and High Demanders

[31] One Low Demander in the experiment chose to spend his entire final period earnings reducing the earnings of his uncooperative group members, which skews the results of Table 4. In order to distinguish between end-game behavior and outcomes prior to the final period (which could still influence group behavior), any results from Table 4 that differ substantially from the overall magnitudes when only the first 9 periods are considered are reported in parentheses.

[32] In Reuben and Riedl (2013), full cooperation required full contributions from all group members, but heterogeneity introduced inequality in payoffs. In contrast, payoffs are equal here under the efficient outcome, but full cooperation requires contributions to differ.

[33] Regressing High Demanders' current period contribution on their previous reductions, we find that those contributing 2 do not respond significantly ($p > 0.57$, clustering standard errors at the group level or $p > 0.63$ at the subject level), while reductions are negatively associated with contributions for those contributing 3 ($p = 0.09$ or $p = 0.04$) or 4 ($p < 0.01$ at both cluster levels).

were largely resistant to increasing their cooperation in response. These results are broadly consistent with prior results suggesting that participants are self-interested in their interpretation of the appropriate contribution norms (e.g., Reuben and Riedl, 2013), although it is striking that this difficulty persists even though the two demand-types face an essentially symmetric situation, with their earnings equalized at each level of cooperation. The results also dovetail with Cason and Gangadharan (2015)'s findings that punishment is used less frequently and its effects are weaker when agents have (homogeneous) interior optima. The authors of that study suggest that, outside of the standard linear game, participants may have greater difficulty determining which contributions should be punished and enforcing the payoff-maximizing outcome.

4.2. Communication and demand revelation

The failure of groups in the Sanctions treatment to identify and punish free-riding High Demanders (in the Private Incentives environment), or to reliably establish a contribution norm (in the Observable Incentives environment), underlines the important role of unrestricted communication in social dilemmas in which cooperation requires heterogeneous behavior. In contrast to punishment, we have thus far seen that groups who can communicate and either have complete information or can share (unverifiable) information are able to achieve high levels of cooperation. In addition, groups that cannot discuss type information sustain lower contributions than those who can. This section further explores these findings by addressing two related questions: whether participants in the Unrestricted Communication treatment use the chat period to truthfully reveal their demand and whether participants use the chat to establish and clarify a norm in which both types make the socially optimal contribution.

When the ability to reveal demand was available in the Private Incentives experiment, participants typically took advantage of it. Most participants in the Unrestricted Communication condition (70%) announced their type in the first period. No one revealed any new or conflicting information after the first period, though some repeated their type for the first few periods. Among those who announced their type, nearly all told the truth. Only two High Demanders falsely claimed to be Low Demanders and these two individuals then behaved as cooperative Low Demanders for the remainder of the experiment.[34] Three of the eleven groups elected not to discuss their types, instead focused on discussing the socially optimal strategy, and experienced similar contributions to the other groups.

We can also consider the question of whether the demand-types of the players were in fact revealed, one way or another, to their group members. Following the experiment, participants were asked how many High Demanders they believed to be in their group. In the Baseline treatment, two-thirds of participants correctly guessed that their group contained two High Demanders and in 40% of the groups demand was "fully revealed," in that all three members correctly guessed the composition.[35] In the Restricted Communication treatment, this percentage was slightly higher: 79% of participants correctly inferred that there were two High Demanders in their group and demand was fully revealed in 55% of groups. While individuals had the ability (and the incentive) to misrepresent their preferences in the Unrestricted Communication treatment, demand was fully revealed in all but one group (91%), in which a High Demander had lied in the chat and successfully misrepresented his or her type.

In order to better understand the differential effectiveness of communication across information environments, we examine the content of the participants' chats. Analyses of the effectiveness of communication in homogeneous, linear public goods games have found that the conversations regularly begin with one group member observing that full contribution would be best for the group, often with subjects stating the payoffs that each group member would receive under the optimum (Brosig et al., 2003).

Table 5 presents the chat results for each group that participated in one of the three communication treatments, including statistics on chat use and the frequency with which groups explicitly mentioned that the strategy of High Demanders contributing 4 tokens and Low Demanders contributing 2 tokens would be best for the group. First, we observe that there is very little difference in chat usage across the three mechanisms. There are no significant treatment differences in either number of messages or total word count over the course of the 10 period experiment.[36] Likewise, there is little difference in the proportion of chats that were directly related to the content of the experiment. However, there is a marked improvement in the ability of groups to identify and come to consensus on the social optimum when they can freely discuss and/or observe their group members' types. Groups in the Restricted Communication condition, who could not reveal their types, focused on making general appeals to cooperation or stating the number of tokens they planned to contribute in the period and they rarely discussed how many tokens each individual or each type should contribute. In contrast, almost every group in the Unrestricted Communication treatments (20 out of 22 groups across both experiments), explicitly discussed a group strategy in which the High Demanders would contribute 4 and the Low Demanders contribute 2. In nearly every case, all three group

[34] The two groups in which High Demanders misrepresented themselves did substantially worse, with average group contributions only 53% of the other groups' contributions. Contributions (as well as earnings) in these two groups were significantly different from the others at the 10% level, in a two-tailed test taking the group as the unit of observation.

[35] If participants guessed randomly, we would expect around 50% would correctly answer that there were two High Demanders.

[36] There are no significant correlations between contributions and overall word count or messages sent in any condition, except in the Unrestricted Communication condition with Private Incentives, in which word count is positively associated with contribution ($p = 0.022$). Note that there is one group in the Restricted Communication (Private Incentives) treatment and one group in the Unrestricted Communication (Observable Incentives) treatment that sent only a single message. In both cases, these groups experienced the lowest average contributions across all other groups in the same treatment.

Table 5
Results of chat periods.

Group	Messages	Word count	Mention optimal contribution for each type	All agree to optimum	Discuss payoff of 80
Restricted Communication (Private Incentives)					
1	33	293	Yes	No	No
2	18	86	Yes	No	No
3	45	138	No	No	No
4	86	334	No	No	No
5	1	1	No	No	No
6	13	63	No	No	No
7	13	42	No	No	No
8	97	332	No	No	No
9	29	172	No	No	No
10	35	284	No	No	No
11	93	415	Yes	Yes	No
Overall	42	196	3	1	0
Unrestricted Communication (Private Incentives)					
1	46	284	Yes	Yes	Yes
2	50	266	Yes	Yes	Yes
3	39	234	Yes	Yes	Yes
4	84	412	Yes	Yes	Yes
5	29	140	Yes	No	No
6	36	186	Yes	Yes	Yes
7	19	101	Yes	Yes	No
8	46	134	Yes	No	No
9	70	304	Yes	Yes	Yes
10	72	397	Yes	Yes	Yes
11	27	67	No	No	No
Overall	47	229	10	8	7
Unrestricted Communication (Observable Incentives)					
1	82	300	Yes	Yes	Yes
2	25	121	Yes	Yes	Yes
3	17	99	No[a]	Yes	Yes
4	11	50	Yes	Yes	Yes
5	24	139	Yes	Yes	Yes
6	176	508	Yes	Yes	Yes
7	122	681	Yes	Yes	Yes
8	54	208	Yes	Yes	Yes
9	20	96	Yes	Yes	No
10	25	388	Yes	Yes	Yes
11	1	1	Yes	No	Yes
Overall	51	236	10	10	10

[a] Participant asked if all agreed to maximize the group earnings, all agreed, and noted payoffs of 80.

members then agreed to follow this strategy. Further, most groups noted that each group member would receive a payoff of 80 under the strategy they had coordinated on. It thus appears that communication is particularly effective and crucial in situations where the social optimum requires different contributions from different group members, as it allows groups to clarify and reach consensus on the socially optimal outcome when the contribution norms may otherwise be ambiguous.

4.3. The Falkinger mechanism

Finally, we turn to the Falkinger mechanism, which generated contribution levels similar to Unrestricted Communication in both experiments. Although the mechanism aligns the Nash equilibrium and the socially optimal outcome, its success in this environment was not guaranteed. The mechanism requires an income transfer from below-average contributors to above-average contributors, implying that, in equilibrium, Low Demanders must pay a fine each period. Specifically, the equilibrium outcome has the two High Demanders contributing 4 tokens, the Low Demander contributing 2 tokens, and 12 points transferred from the Low Demander to the High Demanders. Whereas in the other conditions there was no difference in the payoffs received by the two types under either the Nash equilibrium or the social optimum, High Demanders in this condition are predicted to earn 27% more than Low Demanders. A Low Demander who is averse to this payoff inequality

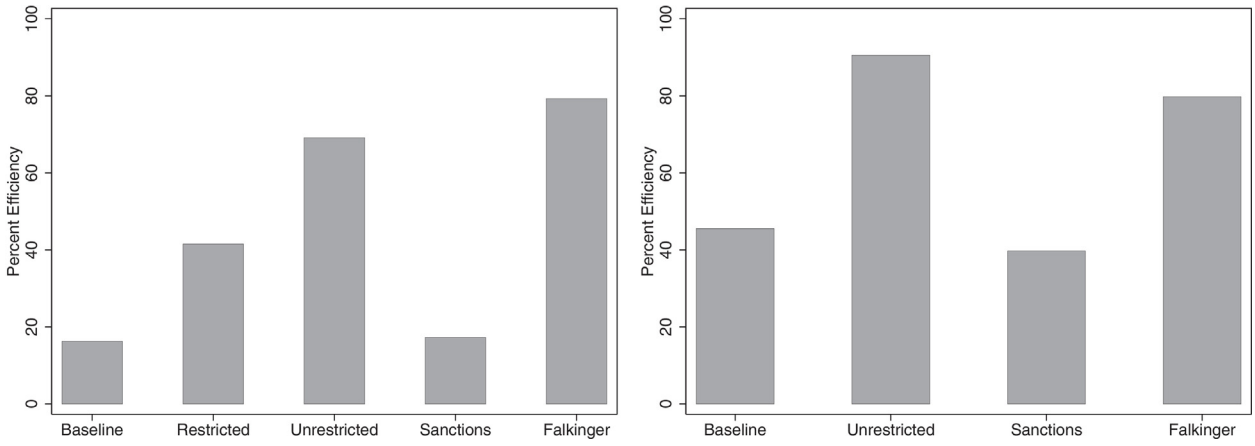

Fig. 5. Percent efficiency reached under each mechanism relative to Nash equilibrium outcome.

might be inclined to withhold contributions, which would earn him only a slightly lower payoff while bringing the payoffs of the High Demanders down much closer to his own.[37]

Alternatively, Low Demanders might interpret the fine as a sign that they are not contributing the correct amount and might experiment with contributing *more* than 2 tokens. This over-contribution would increase total group contributions, but be detrimental to the group's payoffs, thus implying that the outcome is not as efficient as it appears to be in Figs. 3 and 4. An examination of the Low Demanders' contributions indicates that three-quarters contribute the predicted 2 tokens, while others both over- and under-contribute. In fact, nearly every observation of a Low Demander contributing more than 2 tokens occurred under the Falkinger condition.[38] These observations generally occur early in the experiment, in periods 2 through 4, and in each case follow a fine. This suggests that the presence of the fine might lead to some early confusion on the part of the Low Demanders and cause them to consider over-contribution in order to avoid punishment. In contrast, under-contributing tends to *increase* over the course of the ten periods in the Private Incentives experiment and stays constant in the Observable Incentives experiment.

Although over-contribution by the Low Demanders occurs only rarely, it is important to check that this behavior is not driving the success of the mechanism in increasing contributions. Fig. 5 shows the percent efficiency reached under each mechanism, relative to the Nash equilibrium outcome (i.e., (Group Payoff – Nash Payoff)/(Maximum Payoff – Nash Payoff)). We see that the Falkinger mechanism reaches an efficiency close to 80% in both experiments. In neither case is there a significant difference in efficiency between the Falkinger mechanism and Unrestricted Communication, and both always surpass the Baseline in efficiency at all conventional significance levels, while the Sanctions mechanism does not. Additionally, there is no substantive change in the results of Tables 1 and 2 if efficiency replaces total contributions as the dependent variable.[39]

Finally, we note that the success of this mechanism might come at the cost of fairness when socially optimal contributions differ by group member. While High Demanders tend to earn more than Low Demanders in general in the Private Incentives experiment (partially due to the ability of High Demanders to pose as Low Demanders), the gap is by far the widest under the Falkinger mechanism.[40] In the Observable Incentives experiment, there is a large and significant gap in earnings in the Falkinger treatment, *but not* across the other three treatments. Furthermore, in a post-experiment survey, Low Demanders strongly disagreed that the mechanism was fair.[41]

5. Conclusion

For decades, economists have used laboratory public goods games to explore the dynamics of free-riding and the mechanisms that promote cooperation. Yet there has been surprisingly little research on how cooperation is affected when

[37] In equilibrium, High Demanders earn 86 points and Low Demanders earn 68 points. A Low Demander who chose to contribute 0 tokens would receive a payoff of 66 instead and, in doing so, bring each of the High Demanders' payoffs to 72.

[38] 7 out of 7 Low Demander over-contributions (out of 510 observations) in the Private Incentives experiment occurred in the Falkinger treatment, as did 13 out of 16 over-contributions (out of 400 observations) in the Observable Incentives experiment. 10 of the latter observations were a single Low Demander who contributed 3 or 4 tokens for the entire experiment.

[39] The first columns of Tables 1 and 2 are reproduced in the appendix using efficiency as the dependent variable instead of contributions.

[40] There is a 30–40% efficiency gap between the High Demanders and Low Demanders in all conditions except the Unrestricted Communication treatment (where the gap disappears) and the Falkinger mechanism, where it is 80%.

[41] On a 5 point scale from "strongly disagree" to "strongly agree," the average Low Demander response was 1.6. High Demanders were neutral, with an average response of 2.9. Further, comparing across treatments, participants in the Private Incentives experiment believed this mechanism to be significantly less fair than the sanctioning mechanism, which tended to punish only low-contributing Low Demanders.

group members differ in their optimal and equilibrium strategies. This paper adapts the standard voluntary contribution mechanism game to include heterogeneous dominant and socially optimal strategies and investigates the success of costly punishment, unrestricted communication, and centralized bonuses and fines in promoting cooperation in environments with observable and unobservable incentives.

The pattern of contributions in the baseline game is aligned with the standard result that contributions begin midway between Nash and Pareto outcomes and then decline with repetition. However, costly punishment in this environment *does not* generally increase contributions beyond the baseline level. When incentives are private information, participants refrain from punishing anyone except unambiguous free-riders, suggesting that peer monitoring is likely to be less successful in heterogeneous groups when uncooperative behavior cannot be easily identified. Further, even when under-contributors could be identified (as in the case of a Low Demander who fully free-rides or both types in the Observable Incentives experiment), the punishments doled out were not sufficient to increase contributions. Remarkably, communication does lead to high contributions in this environment – both when participants can discuss anything except for their payoffs and, even more so, when they can share information about their payoff-type: Rather than under-reporting their true demands, most participants truthfully reveal their type. When communication is unrestricted, contributions are similar to those under a centralized mechanism that rewards above-average contributors and fines below-average contributors (Falkinger, 1996).

It thus appears that communication is particularly effective and crucial in situations where the social optimum requires different contributions from different group members, as it allows groups to clarify and reach consensus on the socially optimal outcome. Without the ability to communicate, contributions norms in heterogeneous groups may be ambiguous. While most groups in the Sanctions condition were unable to establish a norm of efficient cooperation, even when incentives were observable, groups that could freely communicate agreed to follow the socially efficient outcome in nearly every instance. In contrast, groups in the private information experiment who could not reveal information about their type appear to be impeded in their ability to coordinate on the social optimum. This result underlines the importance of communication as a means of establishing the appropriate contribution for each individual, and indicates that preventing subjects from sharing payoff information can understate the full effect of communication in social dilemmas.

The results suggest avenues for future research. Perhaps the most surprising result is the success of communication in promoting cooperation even when participants can discuss their private values. Despite incentives to be untruthful, 90% of participants revealed their true demands. Though the initial impulse appears to be truth telling, the question remains whether participants would learn with repetition that they can gain by masking their true demands or if, instead, an innate aversion to lying (e.g. Gneezy, 2005) precludes them from doing so. A further investigation in which participants are either regularly rematched into new groups or reassigned new payoffs could address whether the high levels of truth telling are the result of participants failing to realize the incentive to lie until after they have already revealed their types. Another worthwhile extension would be to study the effectiveness of sanctions when there is a broader overlap in the range of plausible contributions for each type. While sanctions generally do not increase the contributions of High Demanders to their socially optimal amount, this extension could address whether the sanction mechanism at least causes the High Demanders to increase their contributions to the socially optimal level for *Low Demanders*.[42] Finally, this framework could be extended to incorporate other mechanisms that have been successful at promoting cooperation. For instance, there is evidence that sanctions and communication interact positively (e.g. Ostrom et al., 1992) and that various mechanisms for endogenous group formation can sustain cooperation (e.g. Page et al., 2005).

Conflicts of interest

The author reports no conflicts of interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jebo.2016.09.012.

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