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Common and private signals in public goods games with a point of no return

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Abstract

We provide experimental evidence on behavior in a public goods game featuring a so-called point of no return, meaning that if the group's total contribution falls below this point all payoffs are reduced. Participants receive either common or private signals about the point of no return, and experience either high or low reductions in payoffs if insufficient contributions are made. Our data reveal that, as expected, contributions are higher if the cost of not reaching the threshold is high than if it is low. High signal values discourage contributions and endanger the likelihood of success when signals are common, but not when signals are private. In addition, successful coordination of contributions is less frequent in a control treatment featuring a standard provision point mechanism than in the experimental treatment where the payoff reduction factor is high, although the theoretical predictions of the two games are similar.

Keywords: Public goods; Provision point mechanism; Experiments; Signal

JEL Classification: H41; C92; C72

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1. Introduction

Public awareness of environmental issues has evolved rapidly over the last decades, emphasizing aspects such as tropical deforestation, desertification, biodiversity, and climate change. Many environmental resources have thresholds that, if surpassed, may have dangerous consequences. There is now a widespread consensus that multilateral effort is needed to protect the environment, but the problem is that each individual actor has an incentive to free-ride on the others' efforts.[1] Motivated by the importance of this kind of public goods requiring collective action to reach a target and avoid joint harm, we designed an experimental scenario in which failure to achieve a pre-specified contribution level results in a universal damage that can be either severe or rather modest. We refer to such a critical level as the "point of no return" because if contributions fall short of this point, everybody suffers and restoring the first-best in terms of efficiency is no longer possible.[2] The universal damage from not reaching the threshold is, however, lower, the closer total contributions are (from below) to the critical level – that is, in the scenario we consider, the public good with its free-riding incentives and its efficiency issues exists even below the point of no return.

Our experimental game combines the essential characteristics of a provision point mechanism (PPM) with those of a voluntary contribution mechanism (VCM). These two mechanisms have been extensively investigated in separation (see Ledyard, 1995, for a survey). Yet, few experimental economics studies have combined them into a unified framework.[3] The most commonly implemented PPM (Isaac et al., 1989) uses a step-level function that requires, for providing the public good, a minimum level of group contributions, which is referred to as the "threshold" or "provision point". If enough contributions are made to reach the threshold, the good is provided. Otherwise, it is destroyed. Our game departs from this standard PPM in that, similar to standard VCMs, the payoff function is linear in contribution levels both above and below the threshold with a constant marginal per capita return from the public good. However, differently from standard VCMs, the payoff function is discontinuous at the threshold: if the sum of the contributions falls short of the threshold, all players' payoffs are reduced

[1] The free-riding problem for common-pool resources has been known since the seminal works of Olson (1965) and Hardin (1968).

[2] Another name often used for this critical level, especially in the context of climate change, is "tipping point" (Lenton et al., 2008; Dannenberg et al., 2011).

[3] Some previous experimental work has been devoted to understanding the relative performance of the two mechanisms (e.g., Rondeau et al., 2005) or to assessing the differences between them (Abele et al., 2010).

by a commonly known factor, which can be either low or high.[4] This game allows us to study situations where positive contributions are always efficiency enhancing, both when the threshold – or point of no return – is surpassed and when it is not surpassed. As a matter of fact, many natural resources are not immediately destroyed when there are not enough contributions. Rather, they are seriously depleted. To check whether the assumption of linear payoff function below the threshold affects behavior, we implement as a robustness check a control treatment with a standard PPM.

The majority of previous experimental work on climate change suggests that fear of the collective detrimental consequences caused by the point of no return does not suffice to overcome the cooperation problem (Milinski et al., 2008; Dannenberg et al., 2011; Tavoni et al., 2011; Barrett and Dannenberg, 2012). The general picture that emerges is that cooperation, though needed, is difficult to sustain. Yet, in the presence of a threshold, overcoming the collective action problem may be a matter not only of cooperation, but also of coordination (for theoretical studies on this topic, see Lindahl, 2012, and Barrett, 2013). Parties may find it easier to cooperate and to sustain mutually preferred outcomes if they could coordinate their efforts. Recognizing the importance of this issue, previous experiments have allowed players to communicate intended contributions (Tavoni et al., 2010; Tavoni et al., 2011; Barrett and Dannenberg, 2012). Here we introduce an alternative and simple method for favoring coordination: we provide each player – prior to any contribution decision – with a signal informing him either reliably or vaguely about the point of no return, specified as the sum of all individual signals. We ask: can the provision of a signal about the point of no return inspire more voluntary cooperation, free-riding incentives notwithstanding?

Such a signal, when it is homogeneous for all group members, corresponds to the scenario in which all parties agree on sharing the burden of the contributions required for meeting the threshold. In case of climate change, for instance, the IPCC delivers a common signal to all countries. Although these signals are in the form of "how much aggregate abatement is needed", rather than on how much each country should do, it is not uncommon in the climate change literature to relate the level of contributions to the level of abatement.[5]

On the other hand, since uncertainty about thresholds and knowledge heterogeneity

[4]This game is akin to that studied theoretically by Barrett (2013) and experimentally by Barrett and Dannenberg (2012). However, in both these previous studies, the cost of missing the threshold is additive. Additionally, the payoff function in Barrett (2013) is not the standard linear VCM function, but assumes linear benefits and quadratic costs.

[5]See, for instance, Barrett (2013) for a theoretical study and Milinsky et al. (2008), Tavoni et al. (2010) or Barrett and Dannenberg (2012) for experimental studies.

(with the possibly resulting inequity considerations) are typically diffuse, we investigate as well a scenario where players' signals are private information and heterogenous (specifically, each group member's signal is independently drawn from the same discrete distribution). The private signal case represents a scenario where separate (intragovernmental) panels hold independent and different views on what needs to be done to reach the target – due, e.g., to their different ability to interpret and process information or to their unequal past appropriation of the resource. Each such panel delivers a signal that, if followed, guarantees to meet the threshold. It is as if the delivered signals were, on average, correct. Obviously, the private signal can be thought of as a means of reducing uncertainty about the threshold, which could be completely dispelled by giving parties the opportunity to communicate their signal before they choose their contributions. Yet, as parties have an incentive to untruthfully report their private signal, we preferred to exclude communication opportunities and rather to examine a situation where the strategy of "contributing one own's signal" allows individuals to reach the threshold with certainty.

The presence of signals (either homogeneous or heterogeneous) changes the game from one of mere cooperation to one involving also coordination, provided that the payoff reduction factor is high. The reason for this is that, when the costs of not providing enough contributions are very high, besides the standard inefficient equilibrium (in which everyone contributes zero), there are other equilibria, the most salient of which requires all players to contribute their signal. This is clearly the equilibrium on which all group members wish to coordinate. However, when signals are private and heterogenous, individuals may fail to follow them for, e.g., fairness reasons. Heterogeneous signals may therefore hamper coordination of contributions.[6] Whether this will happen or not, and to what extent this depends on the loss generated by the failure of reaching the point of no return are the main subject matters of our study. Although we acknowledge that a stylized abstract experimental scenario neglects many crucial aspects of the ongoing environmental debate, it may help us better understand the relative importance of factors that affect successful coordination of contributions.

Our focus on the effects of the point of no return on willingness to contribute connects our work to that of Milinski et al. (2008), who introduce the concept of "collective-risk social dilemma". Milinski and coauthors set up a climate change game in which participants, in groups of six, can invest a certain amount of their endowment in a

[6] Previous experiments on coordination games show that coordination is harder to achieve if players are required to engage in symmetric breaking (i.e., to play different actions, even though their strategy sets and payoff functions are identical). Cooper (1999) and Devetag and Ortmann (2007) provide surveys of coordination game experiments.

"climate account" with the objective of collectively reaching a certain target. If they succeed, every group member keeps any leftover money. If they fail, there is a chance that they lose everything (both the collective fund and their personal money). The results show that, even when faced with the possibility of near-certain doom, only half of the groups collect enough funds. Our game differs from that of Milinski et al. (2008) in two important respects: i) we provide the participants with a coordination device, i.e. the signal, and ii) we use piecewise linear payoff functions (conversely, Milinski and coauthors implement an all-or-nothing scenario). In the attempt to shed more light on the issue, Dannenberg et al. (2011) and Tavoni et al. (2011) add, respectively, threshold uncertainty and inequalities in endowments to Milinski et al.'s experiment, and find that incorporating these more realistic features renders cooperation even harder. Barrett and Dannenberg (2012) conduct an experimental test of the theory presented by Barrett (2013) and confirm that uncertainty about the threshold causes cooperation to collapse.

The rest of the paper is organized as follows. In Section 2 we lay out our game, derive some predictions, and describe the experimental procedures. In Section 3 we present the findings of the experiment. In Sections 4 we discuss the results of additional sessions implementing the standard PPM as control. Finally, in Section 5 we conclude.

2. The experiment design

2.1 *The games*

We consider a four-person threshold public goods game with linearity above and below the threshold. Each player is endowed with 10 points which he can either consume privately or contribute to a public good. Before making his contribution choice, each player i receives a signal, s_i, about the level of contributions T that must be reached by the group as a whole. The threshold T, the point of no return, is the sum of all group members' signals: $T = \sum_{j=1}^{4} s_j$. If the group's total contribution reaches this level, each member earns:

$$\pi_i^0 = 10 - g_i + 0.4 \sum_{j=1}^{4} g_j, \tag{1}$$

where g_i is player i's contribution to the public good. Otherwise, each member's earnings are reduced by the factor $\gamma \in (0,1)$. Thus, player i's payoff equals

$$\pi_i = \begin{cases} \pi_i^0 & \text{if } \sum_{j=1}^{4} g_j \geq \sum_{j=1}^{4} s_j \\ \\ \gamma\pi_i^0 & \text{if } \sum_{j=1}^{4} g_j < \sum_{j=1}^{4} s_j \end{cases} \tag{2}$$

Within this basic setup, we manipulate two dimensions in a factorial design and thus study four treatments. The first treatment dimension concerns the reduction factor γ. In the low cost treatments, we set $\gamma = 0.91$, i.e. everyone's earnings are reduced by 9% if the group's contribution does not reach the threshold. In the high cost treatments, we set $\gamma = 0.50$, implying a reduction in each member's earnings by 50% if the threshold is not met. The second treatment dimension refers to the signal that each subject receives about the threshold. In the case of a common signal, all group members receive the same signal so that the threshold is commonly known. In the case of a private signal, the group members' signals are drawn independently from a uniform distribution and each member just knows his own signal. Thus, subjects can at best probabilistically predict the threshold. Regardless of the treatment, the signals are drawn with equal probability from the set $\{3, 4, 5, 6, 7, 8\}$. Hence, the lowest threshold is 12 and the highest is 32.

This signal mechanism can act as a coordinating device: it provides the group members with a simple and salient strategy to reach the threshold, namely contributing their signal. However, private signals raise two problems. On the one hand, they introduce uncertainty about the actual contribution level that must be reached to avoid joint harm. On the other hand, different signals require people to make different contributions resulting in different payoffs. Because the participants can overcome the uncertainty problem by contributing their own signal, we can study whether they are willing to sacrifice equality of contributions, and payoffs, in order to coordinate on the threshold.

2.2 *Predictions*

First, we present the game-theoretic predictions based on selfish motives. Then, we assess the implications of motives different from monetary payoff maximization.

Let us start from the common signal treatments. Since $s_i = s$ for all i, the game is one with complete information and the threshold T is common knowledge. If the sum of contributions is higher than T, the incentives are like in the standard linear VCM: keeping one point yields a private marginal return of 1, whereas contributing the point yields only 0.4. The same is true if the sum of contributions is lower than T: keeping one point yields a private marginal return of γ, whereas contributing the point yields $\gamma \cdot 0.4$. With free-riding incentives above and below T, there are two candidates for equilibrium: the contribution vector where all players free-ride, namely $\mathbf{g}^* = (0, 0, 0, 0)$, and the contribution vector where all players collectively contribute exactly enough to achieve the threshold, namely $\mathbf{g}^t = (g_1^t, g_2^t, g_3^t, g_4^t)$ with $\sum_{j=1}^4 g_j^t = T$.

General free-riding is a strict equilibrium both when the cost is low and when it is high: since the lowest threshold equals 12, no group member can unilaterally reach the threshold and avoid the point of no return. The existence of the equilibrium $\mathbf{g}^t$ depends on whether a player has an incentive to deviate from this outcome by contributing zero (the most profitable deviation). Specifically, for $\mathbf{g}^t$ to be an equilibrium, we must have $10 - g_i^t + 0.4T \geq \gamma\big[10 + 0.4(T - g_i^t)\big]$ or

$$\frac{1-\gamma}{1-0.4\gamma}(10 + 0.4T) \geq g_i^t \quad \text{for all} \quad i. \tag{3}$$

In the high cost common signal treatment ($\gamma = 0.5$), there exist many contribution vectors satisfying this condition, among which the most salient is the vector where everyone contributes the common signal. If $g_i^t = s$, condition (3) becomes

$$\frac{1-\gamma}{1-0.4\gamma}(10 + 0.4 \cdot 4s) \geq s$$

or

$$\frac{10}{0.6s} \geq \frac{2\gamma - 1}{1-\gamma}. \tag{4}$$

Substituting $\gamma = 0.5$ into (4), the right-hand side equals zero so that inequality (4) is satisfied for any value of the signal s.[7] Thus, in the high cost common signal treatment, "contributing the signal" is an equilibrium. Although there exist other equilibria in which the contributions of those who contribute too little are offset by the contributions of others, such equilibria demand more coordination and are less salient compared to the equilibrium in which each player contributes the signal.

Turning to the low cost common signal treatment, when $\gamma = 0.91$ there are no equilibria in which the players collectively contribute exactly enough to meet the threshold. To show this, consider the lowest possible signal $s = 3$ (implying $T = 12$). The left-hand side of condition (3) then equals 2.094, implying that only contributions of 0, 1, and 2

[7] Suppose that $s = 8$ and that the vector of contributions is $\mathbf{g}^t = (8, 8, 8, 8)$. No player has an incentive to deviate by contributing 0. If a player does so, the threshold would not be met and the player would earn 9.8 points, less than his payoff in case of no deviation (14.8 points).

could guarantee (3). Yet, these contributions do not suffice to reach $T = 12$. Moreover, for $\gamma = 0.91$ the coefficient of T in (3) is smaller than 1 (it equals 0.057) which means that also for values of T greater than 12 inequality (3) cannot be satisfied. Thus, in the low cost common signal treatment, there exists a unique equilibrium in which every player contributes zero.

Consider now the private signal treatments. In this case, s_i is player i's private information (for $i = 1, \ldots, 4$), and thus the game is one with incomplete information. Contributing zero remains a strict equilibrium (the arguments given above apply also to private signals). A further salient equilibrium candidate is, once again, the vector in which each player contributes his signal. This is actually an equilibrium for $\gamma = 0.5$, but not for $\gamma = 0.91$. To see this, suppose that i's group members follow their signals and all together contribute $S_{-i} = \sum_{j \neq i} s_j$. Assume first that player i knows S_{-i}. Then, if i follows his signal, his payoff equals $\pi_i = 10 - s_i + 0.4\big[s_i + S_{-i}\big]$. If i deviates and contributes zero, the threshold is not reached and his payoff is $\pi_i = \gamma\big[10 + 0.4S_{-i}\big]$. Such a deviation is not profitable whenever

$$\frac{1-\gamma}{0.6}(10 + 0.4S_{-i}) \geq s_i. \tag{5}$$

In the high cost private signal treatment ($\gamma = 0.50$), condition (5) is satisfied for all possible signal values because the left-hand side equals at least 11.33 (if $S_{-i} = 9$), which is higher than any possible signal. Conversely, in the low cost private signal treatment ($\gamma = 0.91$), the left-hand side of (5) equals at most 2.94 (if $S_{-i} = 24$), which is below any possible signal. This means that, whatever the values of the signals, if the others follow their signals, i has an incentive to contribute his signal in the high cost private signal treatment, and to contribute zero in the low cost private signal treatment. As this holds for all possible signal values, relaxing the assumption that i knows S_{-i} does not alter the results. This shows that while in the low cost private signal treatment there is a unique (inefficient) equilibrium requiring every player to contribute zero, in the high cost private signal treatment there are other more efficient equilibria, the most salient and plausible of which requires each group member to contribute his signal.

Summing up, according to standard game theory, only general free-riding is an equilibrium in the low cost treatments, for both the private and the common signals. Conversely, general free-riding as well as the outcome where everyone contributes his signal are equilibria in the high cost treatments, whatever the type of signal. This analysis suggests that the following can be expected.

Hypothesis 1: *Contributions are higher in the high cost treatments than in the low* *cost treatments.*

Hypothesis 2: *In the low cost treatments, contributions are negligible.*

Hypothesis 3: *In the high cost treatments, players follow the signals.*

The above hypotheses make predictions regarding contribution levels in the high cost and the low cost treatments, but do not differentiate between the two types of signals.

We get different predictions if we assume that players are not selfishly maximizing their monetary payoffs, but care about fairness, e.g., in the form of inequity aversion (as modeled in Fehr and Schmidt, 1999, and Bolton and Ockenfels, 2000). As Fehr and Schmidt's model implies conditional cooperation (Fischbacher et al., 2001), people may be willing to make contributions different from those suggested by the standard self-interest model if they expect others to do so. In their Proposition 4, Fehr and Schmidt (1999, p. 839) show that if all subjects are sufficiently inequity averse, there are fairness equilibria in which all players make the same contribution. The proposition also provides a condition for asymmetric equilibria. Given the parameters of our game, there is no fairness equilibrium even if only one player contributes less than the others because the model assumes that one dislikes disadvantageous inequality more than advantageous inequality. Thus, in the case of private signals, conditional cooperators may be reluctant to play the equilibrium requiring all group members to follow their signals because such an equilibrium can imply payoff inequality. To see this, consider a player that, in the private signal treatments, gets a high signal. Such a player may believe that some of his fellow members have received lower signals, meaning that in equilibrium they should contribute less and earn more. Aversion to disadvantageous inequality may induce the player with a high signal to contribute less than the signal. On the other hand, an inequity averse player that gets a low signal may be willing to contribute more than the signal in order to obtain equality in payoffs.

The same behavior (lower contributions than the signal for high signal values and higher contributions than the signal for low signal values) can be observed if players compute the expected value of the threshold and contribute their 'fair' share. For instance, if player i gets $s_i = 3$, he expects the threshold to be at 19.5 (i.e., $3 + 3 \times 5.5$, where 5.5 is each player's expected signal). He may thus decide to contribute $19.5/4 = 4.875$ or rounding to the closest integer (since participants in our experiment could only make integer contributions) 5, which is more than the signal. Similarly, if player i gets $s_i = 8$, he may contribute 6.125 or, in our setting, 6, which is less than the signal. If all players follow the strategy to contribute $\frac{s_i+(3\times5.5)}{4}$, the likelihood that they reach the threshold is 57.6% (namely 746 out of 1296 possible combinations of the signals).

These considerations give rise to the following hypotheses.

Hypothesis 4: *Players follow less the signals when these are private rather than common.*

Hypothesis 5: *Players contribute less in the private signal treatments than in the common signal treatments for high signal values, and vice versa for low signal values.*

Maximization of social welfare (measured by the sum of π_i over $i = 1, \ldots, 4$) does not depend on the treatments because, in our setting, social welfare increases piecewise linearly with contributions, with a discontinuity at the threshold. The socially efficient outcome (i.e., the outcome that is maximizing social welfare) is thus to contribute everything.

2.3 *Experimental procedures*

The experiment was programmed in z-Tree (Fischbacher, 2007) and conducted in the experimental laboratory of the Max Planck Institute of Economics (Jena, Germany). The participants were undergraduate students from the Friedrich-Schiller University of Jena. They were recruited using the ORSEE software (Greiner, 2004). Upon entering the laboratory, the subjects were randomly assigned to visually isolated computer terminals. The instructions (which are reproduced, translated from German, in the Appendix) were distributed and then read aloud to establish public knowledge. Before starting the experiment, subjects had to answer nine control questions that tested their comprehension of the rules.

Each session consisted of two phases. In Phase 1, the game was repeated ten times using a stranger matching, i.e., subjects were randomly re-matched in every period.[8] In this phase each point was converted into €0.07. In Phase 2, the subjects were again re-matched, played the game only once, and were paid using a conversion rate of €0.70 per point. The second phase merely serves as a control to examine whether and to what extent successful coordination of contributions hinges upon the financial incentives used in the first phase. Obviously, behavior in Phase 2 is likely to be influenced by the outcomes in the previous periods. Thus, by means of Phase 2, we can investigate whether high stakes affect contribution levels after participants have interacted and made decisions with low stakes.

In both phases, we used the strategy method, i.e., subjects decided how much to contribute for each of the 6 possible signals. Contributions had to be integer values from

[8] We chose this protocol to minimize strategic effects from repeated play.

0 to 10 points.

In each session we had 32 participants and distinguished 2 matching groups of 16 players, guaranteeing 2 statistically independent groups (and hence 2 independent observations) per session. We conducted 12 sessions with a total of 384 participants. We devoted three sessions to each treatment so that we have 6 independent observations per treatment. Each session lasted roughly 90 minutes. Average earnings per subject were €20.21, including a show-up fee of €3.00.

3. Results

Figure 1 shows the average contributions by treatment and signal in period 1 (panel (a)) when participants have no common experience, in period 10 (panel (b)) when participants have gained experience and are influenced by feedback about prior outcomes, and in period 11 (panel (c)) when monetary incentives are increased.[9] The left-hand (right-hand) part of each panel illustrates the results from the private (common) signal treatments.

[Figure 1 about here.]

The effect of the reduction factor (high vs low), the type of signal (common vs private), and the signal value (3, 4, …, 8) on contribution levels is explored in detail via linear regressions, whose results are reported in Table 1. These regressions model contributions as linear functions of the dummy variable d_{HC} (which equals 1 if the reduction factor is high), the dummy variable d_{P} (which is 1 if the signal is private), the signal value *Signal* (reduced by 3 so that the intercept gives the average contribution when the signal is 3), and their interactions. Models 1 and 2 refer to the first phase of the experiment and consider contributions in period 1 and period 10, respectively; Model 3 analyzes data from the second phase (period 11), with high stakes. All the models control for idiosyncratic effects. Specifically, Model 1 has random effect at the individual level, while Models 2 and 3 have random effects both at the individual and the matching group level.[10]

[Table 1 about here.]

[9] The figure includes also the data from the PPM control treatments whose results will be discussed in the following section.

[10] We do not need to control for matching group clustering in period 1 because subjects are assigned to matching groups at random and have no common experience. Conversely, we must control for it after participants have interacted for some periods.

Using the graphs in Figure 1 and the regressions reported in Table 1, we organize the discussion of the results along the hypotheses stated in Section 2.2. We start with Phase 1 (where the constituent game was repeated 10 times) and then analyze the data from Phase 2 (the high-stake control treatment).

Figure 1 indicates that at the beginning as well as at the end of Phase 1 average contributions are higher when the cost of missing the threshold is high rather than low, whatever the type and value of the signals (in panels (a) and (b) the continuous lines are always above the dashed ones). The regressions in Table 1 allow for a formal test of Hypothesis 1. In both Model 1 and Model 2, the coefficient of the dummy d_{HC} is positive and significant and the interaction term $d_{\mathrm{HC}} \times d_{\mathrm{P}}$ is not significantly different from 0, meaning that for $s_i = 3$ contributions are significantly higher in the high cost treatments than in the low cost treatments, irrespectively of the type of signal. Moreover, the coefficient of $d_{\mathrm{HC}} \times Signal$ is, in both models, positive and significant, implying that the higher contribution levels under high costs are maintained for all possible values of s_i whatever the type of signal. Hence, in line with Hypothesis 1, we report the following result

Result 1: *Independently of the type and value of the signals, players contribute, on average, significantly more when the cost of not reaching the threshold is high than when it is low.*

Considering Hypothesis 2, Figure 1 makes it clear that for both types of signals average contributions in the low cost treatments are far from being negligible in period 1, and drop to very low levels in period 10 (the dashed lines in panel (a) are higher than those in panel (b), which are basically flat). Although Hypothesis 2 is not formally testable, it is partially supported by Model 2 in Table 1: the model's intercept is 1.665 and the coefficient of d_{P} is not significant, i.e., in period 10, contribution levels are low irrespectively of whether the signal is common or private. Therefore, we write

Result 2: *In the low cost treatments, regardless of the type and value of the signals, average contributions are not negligible in period 1 and become small (below 2 points) in period 10.*

To gain a graphical insight into Hypothesis 3, we compare, for each treatment with high costs, the continuous line with the dotted gray diagonal line in Figure 1. In the high cost common signal treatment, subjects tend to contribute their signal in both period 1 and period 10 (see right-hand graphs in panels (a) and (b), respectively), although in period 10 this appears to occur only for low signal values. Turning to the high cost private signal treatment, the continuous lines in the left-hand graphs of panels (a) and (b) are not aligned with the corresponding diagonal, suggesting a weak reaction of contributions to signals.[11]

The estimated values of the slope coefficients of the regression lines in Models 1 and 2 (i.e., the *Signal* variable plus the appropriate interaction terms) indicate that in the high cost treatments contributions react positively to signals and confirm that the reaction is stronger in the case of common, rather than private, signals. As a matter of fact, for the high cost common signal treatment the slope coefficients are 0.671 in period 1 and 0.516 in period 10, whereas for the high cost private signal treatment they are 0.326 in period 1 and 0.322 in period 10. Hence, contributions in the high cost treatments increase with the signal value. However, a more rigorous test of Hypothesis 3 requires to verify that the slope coefficients are not significantly different from 1. With this aim, we ran two further linear regressions similar to those reported in Table 1, but with either the high cost common signal treatment or the high cost private signal treatment as the baseline. The results of these regressions show that the coefficients of the slopes are all significantly different from 1 at the 5% level. We therefore conclude that a high payoff reduction factor did not lead participants to perfectly match contributions to signals.

Result 3: *In the high cost treatments, average contributions increase with the signal value. Yet, signals are not perfectly followed, especially when they are private.*

So far we have considered the hypotheses based on selfish preferences, and found that contributions are strongly affected by the cost of missing the threshold (as predicted by Hypothesis 1), although they are not negligible when the cost is low (in contrast to Hypothesis 2) and not perfectly aligned with the signals when the cost is high (contrary to Hypothesis 3). We turn now to compare contributions between the two types of signals. Recall that the type of signal should not matter from a standard game theoretic perspective, but can affect behavior if participants are driven by motives other than self-interest.

We have already seen – in support of Hypothesis 4 – that if the cost of not reaching the threshold is high, the slope coefficients of the private signal regression lines (i.e., 0.326 in period 1 and 0.322 in period 10) are smaller than the slope coefficients of the common signal regression lines (0.671 in period 1 and 0.516 in period 10). The negative coefficient of $d_{\text{HC}} \times d_{\text{P}} \times Signal$ in Model 1 and Model 2 informs us that the differences in slopes are significant. Hence, if costs are high, participants are less willing to contribute their

[11] This difference between private and common signal is in line with Hypothesis 4, predicting that participants follow less private signals than common signals. We will return to this point later.

own signals when these are private rather than common, as predicted by Hypothesis 4.

Considering now the treatments where the cost of not reaching the threshold is low, the dashed lines in Figure 1.(a) indicate that for both types of signals the correlation between contributions and signals is rather weak in period 1, although private signals bring about higher contributions than common signals for all six values of the signal. From Figure 1.(b), we see that in period 10, whatever the type of signal, the correlation between contributions and signals disappears. Hence, Hypothesis 4 does not seem to be validated in the low cost treatments. Once again we use the models in Table 1 to test formally the hypothesis. The insignificant coefficient of $d_{\mathrm{P}} \times Signal$ in Model 1 confirms that, with low costs, the two types of signals do not cause a different reaction of contributions to signals in period 1. This reaction is found to be more pronounced in the case of private signals in period 10 (the coefficient of $d_{\mathrm{P}} \times Signal$ in Model 2 is positive and significant), notwithstanding the flatness of the regression lines. This evidence can be summarized by

Result 4: *In the high cost treatments, participants follow less the signals when these are private rather than common. This is not observed in the low cost treatments.*

We check now if, compared to contributions in the common signal treatments, contribution in the private signal treatments are higher for low signal values and lower for high signal values, as predicted by Hypothesis 5. We know from the previous analysis that if the cost of not reaching the threshold is low, in period 1, contributions under private signals are higher than contributions under common signals over the entire range of possible signals. In fact, they are always weakly significantly higher as indicated in Model 1 (Table 1) by the positive and weakly significant coefficient of d_{P}, and the insignificant coefficient of $d_{\mathrm{P}} \times Signal$. Although in Model 2 the coefficient of d_{P} is not significant, the coefficient of $d_{\mathrm{P}} \times Signal$ is (as noted above) positive and significant, implying that in period 10, contrary to Hypothesis 5, the higher is the value of the signal, the higher are contributions in the low cost private signal treatment compared to contributions in the low cost common signal treatment.[12] Hence, the data from the low cost treatments do not lend support to Hypothesis 5.

Let us turn now to the high cost treatments. In these treatments, at the beginning of phase 1, contributions in response to $s_i = 3$ are slightly higher under private signals (because, in Model 1, the coefficient of d_{P} is positive and weakly significant, and the coefficient of $d_{\mathrm{HC}} \times d_{\mathrm{P}}$ is not significant). Moreover, we know that, if costs are high, the

[12]The last observation must be taken with a pinch of salt because the low cost regression lines are rather flat in period 10.

private signal regression line is flatter than the common signal regression line (because the coefficient of $d_{\mathrm{HC}} \times d_{\mathrm{P}} \times Signal$ is negative and significant). This means that the two regression lines cross each other: for low signal values, contributions in the case of private signals are weakly significantly higher than those in the case of common signals; for high signal values, the former are significantly lower than the latter.[13] Considering Model 2, contributions in the high cost treatments are once again in line with Hypothesis 5 since the coefficient of $d_{\mathrm{HC}} \times d_{\mathrm{P}} \times Signal$ is, also in Model 2, negative and significant.[14] Model 2 differs from Model 1 in the coefficient of d_{P}, which is not significant in period 10, implying that contributions when the signal is 3 do not differ significantly depending on the type of signal. The observations concerning Hypothesis 5 lead us to write

Result 5: *Compared to average contributions in the high cost common signal treatment, average contributions in the high cost private signal treatment are higher for low signal values (weakly significantly higher in period 1), and significantly lower for high signal values. In the low cost treatments, average contributions are always higher if signals are private rather than common.*

Hence, the data provide partial support for Hypotheses 4 and 5, which discriminate between types of signals. Indeed, only if the cost of not reaching the threshold is high, the results are in line with the hypotheses.

To shed some light on efficiency aspects of private-vs-common signals and high-vs-low costs in our game, we compute the probability to meet the threshold (or the likelihood of success) in the various treatments. To proceed with explaining how we calculate this probability, we need to recall that we used the strategy method, i.e., every participant had to write a contribution for each of the six possible signal values. This is not so much of a problem for the common signal treatments because the four members of a group see (and are aware of seeing) the same signal. When participant i decides how much to contribute if, e.g., $s_i = 3$, he knows that his group members are also deciding in response

[13] Estimating Model 1 with $Signal$ reduced by 8 (not 3) – i.e., letting the intercept represent the average contributions when the signal is 8 – and then looking at the coefficient of the interaction between d_{HC} and d_{P} allow for a stringent test of the difference in contributions between the high cost private signal treatment and the high cost common signal treatment when $s_i = 8$. The coefficient of $d_{\mathrm{HC}} \times d_{\mathrm{P}}$ in this regression is negative (-1.657, with a standard error of 0.486) and highly significant (p-value < 0.001), confirming that Hypothesis 5 is supported in the high cost treatments for high signal values.

[14] We estimated also Model 2 with $Signal$ reduced by 8, and found that the coefficient of $d_{\mathrm{HC}} \times d_{\mathrm{P}}$ is negative (-1.821, with a standard error of 0.499) and highly significant (p-value < 0.001), i.e., contributions in response to $s_i = 8$ are significantly smaller in the high cost private signal treatment than in the high cost common signal treatment. Additionally, the coefficient of the dummy d_{P} is positive (0.755 with a standard error of 0.353) and significant at the 5% level, confirming that, for $s_i = 8$, participants contribute significantly more in the low cost private signal treatment than in the low cost common signal treatment.

to $s_i = 3$. Hence, for any group, six combinations of equal signals are possible. For the private signal treatments, things are a little more complicated because when participant i decides how much to contribute if, e.g., $s_i = 3$, he does not know the others' signals, which can be any value in $\{3, 4, 5, 6, 7, 8\}$. A participant's contributions in response to a certain signal can therefore be matched with the contributions made by his group members in response to any possible signal. For any group, $6^4 = 1296$ combinations of signals are possible.

To estimate the likelihood of success of a group, (*i*) first we check, for each combination of signals, whether or not that group meets the threshold, and (*ii*) then we divide the number of times the threshold is met by the number of possible combinations of the signals. We estimate this probability for each group we can form. Because we used a stranger matching procedure in which, in every period, participants were randomly rematched within matching groups of size 16, we have 1820 groups per matching group. Taking the average of the probability of success over all groups within a matching group, we obtain the average probability of success for that matching group. Table 2 presents such average probabilities in periods 1, 10, and 11, separately for each matching group and each treatment. Figure 2 provides a graphical description of the data in periods 1 and 10.[15]

[Table 2 about here.]

[Figure 2 about here.]

Considering only Phase 1 (i.e., periods 1 and 10), it is evident that, with the exception of the low cost treatments in period 10, the likelihood of success is, on average, very high in all treatments. In the high cost treatments, except for two matching groups, the average probability to meet the threshold is above 80% for both types of signals.[16] Hence, the observation that participants follow less the signals when these are private rather than common (Result 4) does not translate into a lower probability of success, on average. The reason is that contributing less than the signal for high signal values is offset by contributing more than the signal for low signal values. In the low cost treatments, private signals do marginally better than common signals on probability of success in period 1 (p-value = 0.065; Wilcoxon rank-sum test, henceforth WRT), whereas the difference between types of signals becomes not significant in period 10 (p-value =

[15]Figure 2 (like Figure 1) shows results for the PPM treatments, which will be analyzed later.

[16]A Wilcoxon rank-sum test does not reject the null hypothesis that the likelihood of success is the same in the high cost private signal treatment and the high cost common signal treatment (p-values equal 0.394 in period 1, and 0.309 in period 10).

0.485).[17] Comparing then the probability of success at the beginning and at the end of Phase 1, we see that, for each matching group and all four treatments, the probability is higher in period 1 than in period 10 (all p-values ≤ 0.031; Wilcoxon signed-rank test, henceforth WSRT). We note, however, that the magnitude of the difference between period 1 and period 10 is much larger for the low cost treatments.

Although on average common and private signals do not lead to different probabilities of success, Figure 1 suggests that in the common signal treatments such probabilities may depend on the signal values, especially when the cost of not reaching the threshold is low. We find indeed that, at the beginning of phase 1, in the high cost common signal treatment the probability to meet the threshold is 100% for $s_i \leq 6$ and 84% for $s_i = 8$. In the low cost common signal treatment such a probability decreases constantly with the signal value: it is about 100% for $s_i = 3$ and becomes 25% for $s_i = 8$. Similar patterns are observed in period 10, where low costs yield a much more severe decline in probability of success with signal value as compared to period 1. It seems therefore that, in the case of low costs, the higher the known level of the threshold, the less likely that the threshold will be met.

Table 3 complements the analysis on efficiency by reporting the average social welfare by matching group and treatment in period 1, 10, and 11 (see also Figure 3 for a more concise graphical representation). The values are obtained using the same procedure as described above for the likelihood of success, except that here we consider, for each group, the sum of the members' payoffs for all combinations of signals and then take the average over all 1820 groups within a matching group.

[Table 3 about here.]

[Figure 3 about here.]

The average social welfare so computed does not vary with the type of signal when costs are high (p-values ≥ 0.240 for both period 1 and period 10, WRT). When costs are low, the difference in social welfare between types of signals is not significant in period 10 (p-value = 0.512, WRT), but marginally significant in period 1 (p-value = 0.093). In the common signal treatments, social welfare is always higher when costs are high rather than low (p-values in periods 1 and 10 are, respectively, 0.009 and 0.002, WRT). In the private signal treatments, high costs outperform low costs only in period 10 (p-values = 0.009 in period 10 and 0.301 in period 1, WRT). Hence, although in the high cost treatments individual payoffs are reduced by 0.50, rather than 0.91, when the

[17] All reported statistical tests are two-sided.

threshold is not met, high cost treatments fare better than low cost treatments in terms of social welfare because high costs lead to a very high likelihood of success. Given the general decay in contributions and probabilities of success observed when subjects gain experience, it is not surprising that, in each treatment, social welfare is significantly smaller in period 10 than in period 1 although the magnitude of the reduction is much larger under low costs (p-values ≤ 0.031 for the low cost treatments and the high cost private signal treatment, p-value $= 0.062$ for the high cost common signal treatment, WSRT).

We conclude this section by analyzing the data from Phase 2. This will provide insight into whether participants are affected by high stakes after having experienced low stakes for ten periods. Panel (c) in Figure 1 shows that, in each of the four treatments, contributions in period 11 follow the same pattern as those in period 10. This observation is corroborated by the estimates of Model 3 in Table 1, which are qualitatively similar to those of Model 2: with one exception, all significant coefficients have the same sign and are of similar magnitude.[18]

As for the probability to meet the threshold (see Table 2), Wilcoxon signed-rank tests fail to reject the null hypothesis of no difference in likelihood of success between period 10 and period 11 when signals are private (p-values $= 0.437$ under high costs and 0.219 under low costs), and reject it at the 10% significance level when signals are common (p-values $= 0.062$ under high costs and 0.094 under low costs). The introduction of high stakes does not have a major impact on social welfare either (see Table 3). Except for the low cost common signal treatment (where the difference in social welfare between period 10 and period 11 is marginally significant, p-value $= 0.062$, WSRT), for all the other treatments no statistically significant difference in social welfare is observed when comparing period 10 and period 11 (all p-values ≥ 0.312, WSRT). Overall, these results suggest that the Phase 1 results are robust to changes in the provided financial incentives.

4. Varying the constituent game

Our experimental game assumes that individual contributions benefit the other group members both below and above the threshold. To assess whether such a feature gives rise to different behavior than a 'pure' PPM, we run two control treatments with the standard PPM. In one treatment the signals are common; in the other they are private.

[18]The only exception is the variable *Signal*, which is negative but not significant in Model 3, indicating that, in period 11, contributions do not decline significantly with the signal when costs are low and signals are common.

In line with the other experimental treatments, the four group members receive a signal (either common or private) about the threshold T $(= \sum_{j=1}^{4} s_j)$ and, if the threshold is reached, each member earns the payoff specified in (1). But now, if fewer than T points are collectively contributed and the threshold is not reached, contributions are lost. Thus, player i's payoff is

$$\pi_i = \begin{cases} \pi_i^0 & \text{if } \sum_{j=1}^{4} g_j \geq \sum_{j=1}^{4} s_j \\ \\ 10 - g_i & \text{if } \sum_{j=1}^{4} g_j < \sum_{j=1}^{4} s_j \end{cases} \tag{6}$$

In the PPM treatments – like in the high cost treatments – besides the inefficient equilibrium where each player contributes zero, there is a multiplicity of equilibria where the group members collectively contribute exactly enough to reach the threshold. Contributing one's own signal is the most salient of such efficient equilibria. Contributions in the PPM treatments are therefore expected to be similar to those in the high cost treatments.

The PPM control treatments followed the same procedures as those described in Section 2.3. We ran three sessions per treatment. Each session involved 32 participants and had two matching groups of 16 players, guaranteeing 6 independent observations per control treatment.

In presenting the results, once again we start with Phase 1. First we provide evidence on contributions, and then we move to an analysis of efficiency. Figure 1 gives rise to two observations. (i) In all cases except one – namely, private signals in period 1 – average contributions in the PPM treatments (dot-dashed lines) lie between those in the high cost treatments and those in the low cost treatments. Thus, contrary to standard (game-)theoretical predictions, the PPM treatments induce, in general, lower average contributions than the high cost treatments. (ii) In the PPM treatments, the correlation between contributions and signals is rather weak, especially in periods 10.

Statistical support for these observations is presented in Table 4, reporting the results of three linear models using data from the high cost and PPM treatments in period 1 (Model 1), period 10 (Model 2), and period 11 (Model 3).[19] In each model, contributions are regressed on the same variables as those used in Table 1.

[Table 4 about here.]

[19] We are interested in comparing contributions across the treatments yielding the same theoretical predictions.

In both Model 1 and Model 2, the estimated coefficients of d_{HC} and $d_{\mathrm{HC}} \times d_{\mathrm{P}}$ are not significantly different from zero, meaning that, at the beginning as well as at the end of Phase 1, for $s_i = 3$ contributions in the high cost and PPM treatments are about the same. Yet, the coefficient of $d_{\mathrm{HC}} \times \mathit{Signal}$ is positive and significant, and so is the sum of the coefficients of $d_{\mathrm{HC}} \times \mathit{Signal}$ and $d_{\mathrm{HC}} \times d_{\mathrm{P}} \times \mathit{Signal}$ (which equal 0.258 in period 1 and 0.312 in period 10).[20] This indicates that, for both types of signals, contributions in the two treatments diverge when the signal increases: the higher the signal, the larger the difference between contributions in the high cost treatments and contributions in the PPM treatments in both period 1 and period 10.

The coefficients of *Signal* and $d_{\mathrm{P}} \times \mathit{Signal}$ inform us about the reaction of contributions to the two types of signal in the PPM treatments. In Model 1, the coefficient of *Signal* is positive and significant, i.e., contributions increase with signals if these are common. Conversely, by adding the coefficients of *Signal* and $d_{\mathrm{P}} \times \mathit{Signal}$ so as to assess the reaction under private signals, we obtain a value (namely 0.068) that is not significantly different from zero.[21] Similar conclusions are obtained from Model 2, where the effect of common signals on contributions is even negative. We thus conclude that participants hardly follow private signals in the PPM treatments.

Notwithstanding the weak reaction of contributions to private signals, both PPM treatments perform reasonably well in terms of likelihood of success and social welfare (see Figures 2 and 3, respectively) especially in period 1. The reason also in this case is that, at the beginning of phase 1, if signals are private the lower contributions of the high signal-players are counterbalanced by the higher contributions of the low signal-players so that there is no difference in probability of success and social welfare between the types of signals (p-value ≥ 0.394 in both cases, WRT). Probability to meet the threshold and social welfare decrease significantly in period 10 (all p-values ≤ 0.031, WSRT), but once again they do not differ depending on the type of signal (p-value ≥ 0.818 in both cases, WRT).

The average contributions depicted in Figure 1 suggest that, at the beginning of Phase 1, it may be more difficult to meet the threshold for high, rather than low, signal values when signals are common. In fact, we find that, in this case, the likelihood of success is close to 100% for $s_i \leq 4$ and decreases constantly with the value of the signal (it is 45% for $s_i = 8$). This result confirms that of Cadsby and Maynes (1999) who, in a standard PPM, find that a high threshold discourages provision in the absence of a

[20]Linear regressions with the private signal PPM treatment as baseline show that the standard errors are 0.060 in period 1 and 0.061 in period 10.

[21]To test this, we estimate the regression using the private signal PPM treatment as baseline. The slope coefficient of this regression – i.e., *Signal* – is not significant (standard error = 0.0422).

money-back guarantee. The reason put forward for this behavior is that a high known threshold increases, *ceteris paribus*, the risk of contributing.

Despite the good performance in terms of efficiency, compared to the high cost treatments, the control treatments yield, in both period 1 and period 10, a lower probability to meet the threshold (both p-values ≤ 0.009 if the signal is common; p-values ≤ 0.093 if the signal is private, WRT) and, in turn, a lower social welfare (under common signals, regardless of the period, the difference in social welfare between the two treatments is significant at the 5% level; under private signals, the difference is significant at the 10% level in period 10 and insignificant in period 1, p-value = 0.132, WRT).

Finally, we consider the effect of high stakes on contributions in the PPM treatments. Comparing Models 2 and 3 in Table 4, we see that varying financial incentives does not have a major impact on behavior. The regression coefficients in Model 3 display the same sign and statistical significance as those reported in Model 2, except for the coefficient of d_{HC} which is significant at the 10% level in Model 3. As for efficiency, high stakes are found to affect neither likelihood of success nor social welfare.

5. Conclusions

Free-riding and coordination difficulties are thought to be primarily responsible for the breakdown of cooperation in social dilemma situations in general, and in the management of common resources in particular. Providing enough contributions becomes essential if – like in the experimental scenario implemented here – the situation features a so-called point of no return, i.e., a contribution threshold that needs to be reached to avoid universal damage. Participants receive signals about the point of no return, which is defined as the sum of all signals. One can think of the signals as threshold's indicators that are observed by each party separately, but are on average correct. The signals allow us to investigate whether the coordination of contributions and the ensuing successful cooperation hinge upon the type of signal provided (common vs private). In our experiment, subjects facing a point of no return have a natural way to coordinate their actions and avoid joint harm, namely following their signals.

In line with the predictions of the standard self-interest model and the results of previous experimental studies (e.g., Milinski et al., 2008), we observe that contribution levels and likelihood of success are higher when the costs of not reaching the threshold are high. Although the standard model makes no prediction as to the different types of signals, we provide evidence that, compared to common signals, private signals are followed less frequently. As a matter of fact, we find that in case of private signals and high costs, people who see a high signal value contribute less than the signal, whereas those who see a low signal value contribute more than the signal. Whatever the motivation for this behavior – e.g., conditional cooperators disliking payoff inequalities or participants contributing the fair share of the expected threshold – the different reactions to signal values counterbalance each other, with the result that the two types of signals do not differ in likelihood of success and social welfare. We cannot even exclude that the result is driven by a self-serving bias of what contribution would be fair, which has been reported by, e.g., Tavoni et al. (2011) for a collective-risk social dilemma. In the absence of a post-experimental questionnaire designed to measure fairness perceptions, it remains difficult to investigate whether the bias was decisive for our finding.

Interestingly, our data indicate that the standard provision point mechanism results in lower contributions and lower social welfare than the high cost treatments, even though the theoretical predictions of the two games are similar. One possible explanation lies in the different incentives offered by the two games if the threshold is not reached. In the PPM treatments, only those who contribute bear the cost of the failure. Conversely, in the high cost treatments, the cost of not reaching the threshold is universal, and thus free-riders bear it too. This may induce people in the high cost treatments to contribute more than they otherwise would in order to avoid the general loss.

Future research should explore the robustness of these results while at the same time bringing more realism into the game. For example, settings including communication among parties (like in Tavoni et al., 2011) or group representatives who make decisions on behalf of the group (like in Song, 2008) may be worthy of investigation.

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Appendix. Experimental instructions (originally in German)

Thank you for participating in this experiment. Please read the following instructions carefully. It is strictly forbidden to talk to the other participants. In the event of communication, the session will be terminated and no payments will be made. If you have questions, please ask us. During the experiment, we shall not speak of euros but of points. Points are converted to euros at the following exchange rate: **1 point = 7 cents**. At the end of the experiment, you will receive the points you earned during the experiment plus €3 show-up fee. The experiment consists of 10 periods. In each period, you will be placed in a group of four people. The formation of the group changes at random after every period. So your group consists of different people in all 10 periods. Except for us – the experimenters – no one knows who is in which group.

Description of the experiment

At the beginning of each period, you (as well as the other members of your group) receive an endowment of 10 points. You have to decide how many of these 10 points you want to contribute to a group project and how many you want to keep for yourself. You can contribute any amount between 0 and 10 points. The points contributed to the project determine the income of your group. We will explain how this income is calculated in two steps. First, you will learn how your "gross income" is computed. This gross income coincides with your actual income if your group contributes enough to the project. Otherwise, there is a reduction in the gross income. You will learn about this reduction in the second step.

Step 1: Gross income

The period-gross income is composed of two parts:

1. income from the points you keep;
2. income from the group project.

We shall now explain how these two components are calculated.

1. You can keep the points that you do not contribute for yourself (they yield income just for you). Therefore, your income from the points you keep is:

10 – your contribution to the project.

The more you contribute to the project, the lower your income from the points you keep.

2. The income from the group project is determined by multiplying the sum of the contributions of all group members by 0.4:

$$0.4 \times \text{sum of all contributions to the project.}$$

This means that every point you contribute to the project increases each group member's income by 0.4 points. Likewise, each point contributed by another member of your group increases your income by 0.4 points. If, for example, you contribute 4 points and the other members of your group contribute 2, 6, and 8 points, you will receive: 6 [income from the points you kept] + 8 [income from the group project (0.4×20)] = 14 points.

Step 2: Determination of the reduction

Your gross income will be your actual income only if your group reaches a critical contribution sum. If your group does not reach this critical sum, your actual income will be 50% [91%] of your gross income. How is this critical contribution level determined? All group members will be randomly assigned a number between 3 and 8.

[*Participants in the common signal treatment read:* All 6 random numbers are equally likely. All members of your group receive the same random number. The sum of the random numbers determines the critical contribution sum. If, for example, you receive random number 5, your group must contribute, in total, at least $4 \times 5 = 20$ points in order for your income not to be reduced. If your group contributes 19 points or less, then your gross income will be reduced by 50% [91%].]

[*Participants in the private signal treatment read:* The random numbers that the group members receive are independent from each other. This means that the probability that you receive, for instance, random number 4 does not depend on whether another person in your group receives 4; likewise the probability that another person in your group receives a certain random number does not depend on which random number you receive. The sum of the random numbers determines the critical contribution sum. If, for example, you receive random number 5 and the other three members of your group receive 3, 7, and 4, your group must contribute, in total, at least $5 + 3 + 7 + 4 = 19$ points in order for your income not to be reduced. If your group contributes 18 points or less, then your gross income will be reduced by 50% [91%]. You will learn only your own random number; i.e., you will not be informed of the others' random numbers.]

Let's consider a few concrete examples.

Example 1

Your random number is 3. [*Participants in the private signal treatment read:* The random numbers of the other members of your group are 5, 5, and 4.] You contribute 5 points to the project and the others contribute 0, 1, and 3 points. The critical contribution sum is [*in the common signal treatment:* $4 \times 3 = 12$] [*in the private signal treatment:*

$3+5+5+4=17$]. Your group's total contribution is $5+0+1+3=9<$ [*in the common signal treatment:* 12] [*in the private signal treatment:* 17]. This means that you only get 50% [91%] of your gross income, which is 10–5 + 0.4 × 9 = 5 + 3.6 = 8.6. Thus, your period-income is 4.3 [7.83].

Example 2

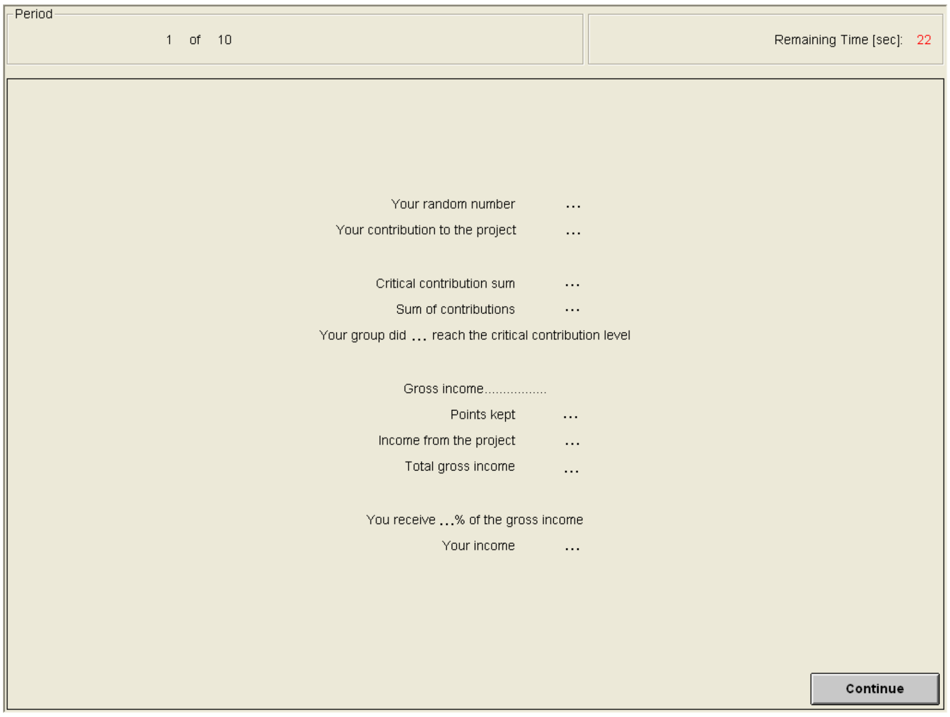
Your random number is 7. [*Participants in the private signal treatment read:* The random numbers of the other members of your group are 6, 8, and 8.] You contribute 6 points to the project and the others contribute 7, 9, and 9 points. The critical contribution sum is [*in the common signal treatment:* $4\times7=28$] [*in the private signal treatment:* $7+6+8+8=29$]. Your group's total contribution is $6+7+9+9=31>$ [*in the common signal treatment:* 28] [*in the private signal treatment:* 29]. This means that you get 100% of your gross income, which is 10–6 + 0.4 × 31 = 4 + 12.4 = 16.4. Thus, your period-income is 16.4.

Procedure on the computer

You must make your contribution decision before learning your random number. This means that you must indicate how many points you want to contribute to the project for each possible random number. In each period, you will see the following decision screen. You have to insert how many points you want to contribute to the project into each input box—conditional on the indicated random number. You must input a contribution between 0 and 10 in each of the 6 input boxes. At the end you must confirm your decisions by clicking the OK button. You can revise your decision as long as you have not clicked OK.

Income information screen

At the end of each period, you will see the following screen informing you about: 1) your random number, 2) the critical contribution sum, 3) how much your group contributed, in total, to the project, 4) whether it reached the critical contribution level or not, and 5) your gross and final income.



Second Experiment

We will now conduct another experiment. The rules and the decision situation are the same as in the previous experiment, except that now:

a) there is only one period, and

b) points are worth more; in particular 1 point = 70 cents.

After this period is over, the whole experiment is finished and you will receive your income from both experiments plus 3 euros show-up fee.

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Table 1: Linear mixed models (estimated by REML) on contribution decisions. The baseline is the low cost common signal treatment.

Model	1 (Period 1)	2 (Period 10)	3 (Period 11)
Intercept	3.113 (0.243)***	1.665 (0.249)***	1.916 (0.240)***
d_{HC} (=1 if $\gamma = 0.5$)	0.810 (0.344)*	2.317 (0.353)***	1.986 (0.340)***
d_{P} (=1 if private signal)	0.608 (0.344)°	0.064 (0.353)	−0.441 (0.340)
Signal	0.341 (0.037)***	−0.099 (0.035)**	−0.034 (0.034)
$d_{\mathrm{HC}} \times d_{\mathrm{P}}$	0.018 (0.486)	−0.162 (0.499)	0.506 (0.481)
$d_{\mathrm{HC}} \times$ *Signal*	0.330 (0.052)***	0.615 (0.049)***	0.684 (0.048)***
$d_{\mathrm{P}} \times$ *Signal*	−0.010 (0.052)	0.138 (0.049)**	0.122 (0.048)*
$d_{\mathrm{HC}} \times d_{\mathrm{P}} \times$ *Signal*	−0.335 (0.073)***	−0.332 (0.069)***	−0.417 (0.068)***
σ_{id}	2.116	2.177	2.126
σ_{MG}	–	0.106	0.001
σ_{e}	1.506	1.414	1.399
LogLik	−4710.839	−4599.06	−4568.942
Observations	384 × 6	24 × 16 × 6	24 × 16 × 6

Note: Standard errors are given in parentheses. Significance codes: '***' p-value < 0.001; '**' p-value < 0.01; '*' p-value < 0.05; '°' p-value < 0.1.

Table 2: Average probabilities to meet the threshold by treatment and matching group in periods 1, 10, and 11.

Common signal

	Period	MG 1	MG 2	MG 3	MG 4	MG 5	MG 6	All
Low Cost	1	60.29%	66.86%	67.55%	57.96%	75.38%	67.01%	65.84%
	10	20.33%	20.62%	28.67%	20.66%	19.41%	14.28%	20.66%
	11	22.64%	31.37%	38.53%	32.50%	10.82%	24.39%	26.77%
High Cost	1	98.75%	88.27%	99.24%	98.46%	96.25%	91.63%	95.43%
	10	82.65%	77.88%	94.92%	96.78%	91.84%	90.29%	89.06%
	11	96.55%	94.66%	97.48%	97.44%	91.53%	90.75%	94.73%

Private signal

	Period	MG 1	MG 2	MG 3	MG 4	MG 5	MG 6	All
Low Cost	1	69.68%	92.20%	90.46%	85.85%	76.11%	59.46%	78.96%
	10	10.77%	29.82%	39.43%	5.89%	14.55%	0.44%	16.82%
	11	6.04%	27.78%	18.86%	7.87%	4.70%	2.95%	11.37%
High Cost	1	90.83%	91.77%	97.65%	98.64%	95.86%	88.23%	93.83%
	10	81.26%	81.30%	83.65%	95.52%	64.17%	85.89%	81.97%
	11	86.01%	84.23%	91.55%	96.04%	82.64%	63.98%	84.07%

Table 3: Average social welfare by treatment and matching group in periods 1, 10, and 11.

Common signal

	Period	MG 1	MG 2	MG 3	MG 4	MG 5	MG 6	All
Low Cost	1	46.89	47.82	48.01	46.76	50.96	47.86	48.05
	10	40.27	40.19	41.78	41.12	39.33	39.40	40.35
	11	40.90	41.96	43.48	42.62	38.86	41.34	41.53
High Cost	1	53.72	48.70	54.46	53.95	52.49	50.41	52.29
	10	46.91	45.62	53.17	52.60	50.75	50.58	49.94
	11	52.67	51.37	54.11	52.27	50.52	50.64	51.93

Private signal

	Period	MG 1	MG 2	MG 3	MG 4	MG 5	MG 6	All
Low Cost	1	48.69	52.44	51.69	50.51	49.64	47.15	50.02
	10	40.64	43.32	44.68	39.58	40.68	37.90	41.13
	11	39.82	43.11	42.23	40.21	39.12	39.07	40.59
High Cost	1	50.21	50.26	53.04	53.69	51.98	49.08	51.38
	10	46.60	46.55	47.42	51.56	41.38	48.56	47.01
	11	48.67	47.83	50.02	51.92	47.98	41.09	47.92

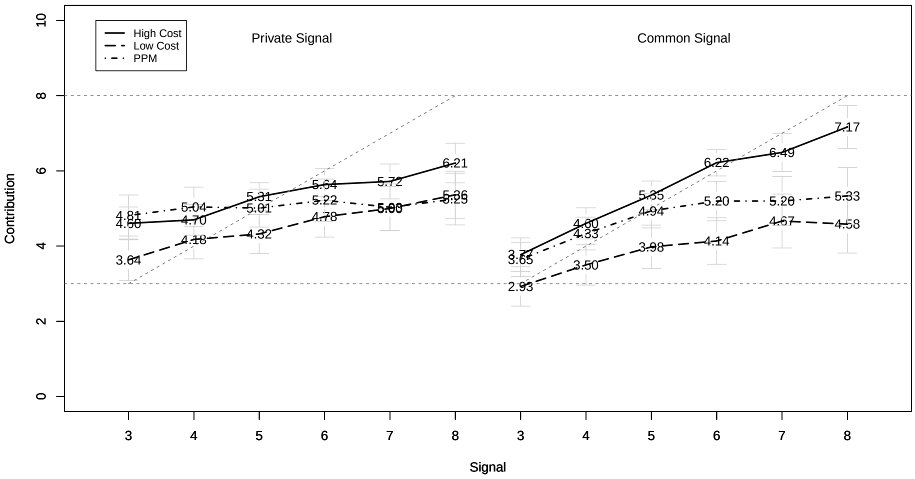
Table 4: Linear mixed models (estimated by REML) on contribution decisions. The baseline is the common signal PPM treatment.

Model	1 (Period 1)	2 (Period 10)	3 (Period 11)
Intercept	3.968 (0.227)***	3.339 (0.459)***	3.058 (0.339)***
d_{HC} (=1 if $\gamma = 0.5$)	−0.046 (0.321)	0.642 (0.650)	0.843 (0.479)°
d_{P} (=1 if private signal)	0.924 (0.321)**	0.113 (0.650)	−0.239 (0.479)
Signal	0.323 (0.042)***	−0.179 (0.043)***	−0.263 (0.040)***
$d_{\text{HC}} \times d_{\text{P}}$	−0.298 (0.454)	−0.210 (0.919)	0.304 (0.678)
$d_{\text{HC}} \times Signal$	0.349 (0.060)***	0.696 (0.061)***	0.913 (0.057)***
$d_{\text{P}} \times Signal$	−0.255 (0.060)***	0.190 (0.061)**	0.346 (0.057)***
$d_{\text{HC}} \times d_{\text{P}} \times Signal$	−0.090 (0.084)	−0.384 (0.086)***	−0.638 (0.080)***
σ_{id}	1.836	2.320	2.349
σ_{MG}	–	0.910	0.507
σ_e	1.730	1.755	1.639
LogLik	−4933.539	−4599.060	−4917.720
Observation	384 × 6	24 × 16 × 6	24 × 16 × 6

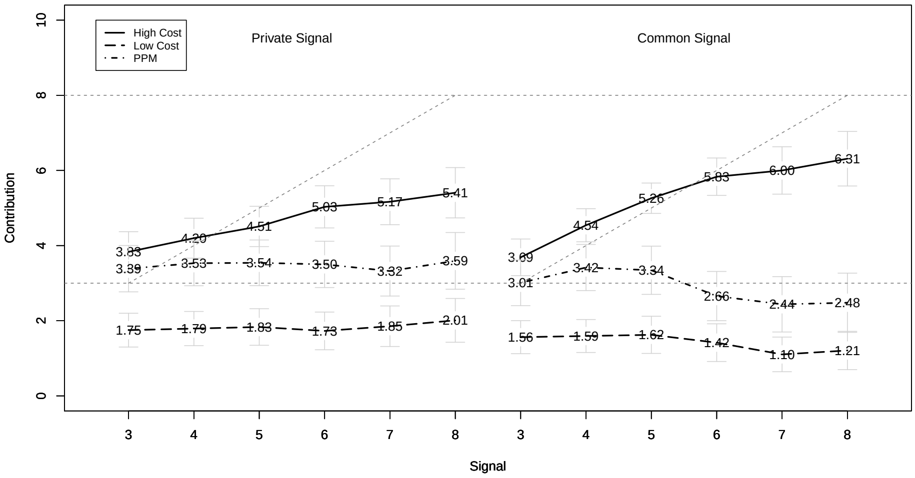
Note: Standard errors are given in parentheses. Significance codes: '***' p-value < 0.001; '**' p-value < 0.01; '*' p-value < 0.05; '°' p-value < 0.1.

Figure 1: Average contributions by treatment and signal in periods 1, 10, and 11.

(a) Period 1



(b) Period 10



(c) Period 11 - High stakes

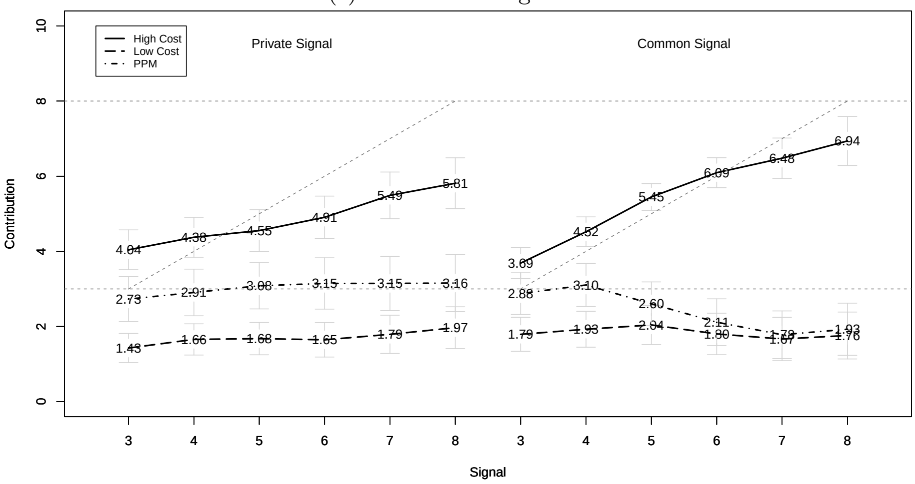


Figure 2: Average probabilities to meet the threshold by treatment in period 1 (P 1) and period 10 (P 10). The six large dots connected by solid lines represent the six matching groups. The number above, and the height of, each bar denotes the average probability of success over all matching groups in the corresponding treatment.

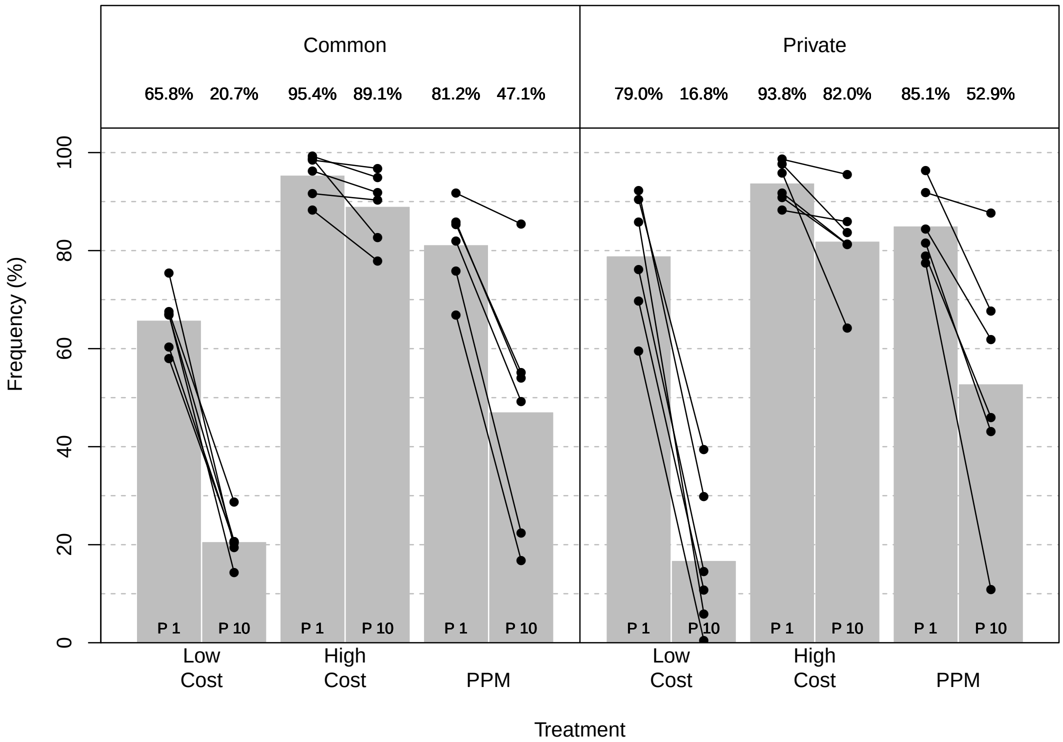


Figure 3: Average social welfare by treatment in period 1 (P 1) and period 10 (P 10). The six large dots connected by solid lines represent the six matching groups. The number above, and the height of, each bar denotes the average social welfare over all matching groups in the corresponding treatment.