# Monitoring in Teams: Using Laboratory Experiments to Study a Theory of the Firm

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**Abstract**

Alchian and Demsetz's (1972) influential explanation of the classical business firm argues that there is need for a concentrated residual claim in the hands of a central agent, to motivate the monitoring of workers. We model monitoring as a way to transform team production from a collective action dilemma with strong free riding incentives to a productivity-enhancing opportunity with strong private marginal incentives to contribute effort. In an experiment, we have subjects experience team production without monitoring, team production with a central monitor, and team production with peer monitoring, then vote on whether to employ the central monitor, who gets to keep a fixed share of the team output, or to rely on peer monitoring, which entails a coordination or free riding problem. Our subjects usually prefer peer monitoring but they switch to the specialist when unable to successfully self-monitor. We provide evidence for situations in which team members resist the appointing of a central monitor and succeed in overcoming coordination and free riding problems as well as for a situation in which an Alchian-Demsetz-like firm "grows" in the laboratory.

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# 1 Introduction

What accounts for the structure of the capitalist firm, in which equity suppliers or their agents hire and supervise workers given few or no residual claims? In an influential paper about the theory of the firm, Alchian and Demsetz (1972) characterized team production by the following four properties: 1. there exist several input providers, 2. the combined output is larger than the sum of the outputs that the individual input providers can achieve by working alone, 3. there is an observable team output but no observable output of the individual input provider, and 4. it is possible but costly to measure the amount of input contributed by each individual provider. The central dilemma of team production, they argued, is that the benefits of working as a team (e.g. benefits from economies of scale or of specialization) may be undercut by the incentive that each team member has to free ride if compensated according to team output rather than personal input. To mitigate this problem, team members' rewards must be tied to their contributions, but that requires another costly input – monitoring – and this in turn gives rise to another collective action problem if monitoring is to be supplied by the team members themselves. The classical capitalist firm solves this problem, they argue, by making one specialized agent the monitor of the other team members who pays them according to their ob served inputs. The central agent is motivated to monitor by the fact that he keeps all team revenue above his contractual obligations to the input providers.

We understand Alchian and Demsetz's depiction of team production in the absence of monitoring to be an example of the familiar problem of collective action or incentives in teams that has been studied by experimental economists in recent decades under the heading Voluntary Contribution Mechanism (VCM) or Public Goods Game (PGG). In a VCM or PGG, subjects are grouped with others and each decides how much of a certain endowment to contribute to a group project and how much to hold for herself. Contributions to the project are scaled up by the experimenter, such that there is a social optimum of contributing. However, since the resulting revenues are divided equally among team members, the individual optimum is contributing nothing. We interpret Alchian and Demsetz as saying that if a sufficient investment is made in monitoring individuals' contributions, then they can be paid according to their contributions, rather than an equal per capita share, as a result of which there will be an incentive to contribute and not to free ride.

We present a simple theoretical model corresponding to this structure, and we investigate how real decision-makers respond to the structure by having subjects make potentially rewarding/costly decisions under it in a laboratory experiment. In the model and experiment, monitoring can either be done by a specialized agent, who is assigned a fraction of the team's joint output, or by the team members themselves, who are then compensated for their contributions to production but not for their monitoring itself. Suppose that agents care only about increasing their own earnings, know one another to be of the same type, and are rational. Then if the only monitoring were to be that done by the team members themselves, there would be a considerable possibility that monitoring would not suffice and hence that the production stage of the model would be a simple VCM, for which there is a straightforward prediction of zero contributions. If, instead, a specialist were offered a sufficient fraction of team output and permitted to monitor, it would be in the specialist's interest to monitor enough to make contributing to team production rational for each team member. With appropriate specifications of returns to team production and of the share claimed by the specialist, team members earn more producing together with a specialist monitor than having no monitor and producing individually. If allowed to vote at no cost – a proxy for workers' choice among organizational forms in a market economy – the model predicts that team members will vote to hire the specialist unless they manage to successfully monitor themselves.

We carry out experimental play of such a model. We vary the conditions under which team members and specialists can learn about their tasks by varying the order in which play occurs (a) with no monitoring, (b) with monitoring (if any) by team members, and (c) with monitoring (if any) by a specialist, before having several opportunities to vote on which kind of monitoring to use, more periods of play, and opportunities to vote again. We also vary the costliness of monitoring for team members versus specialists, and whether or not there exist peer monitoring equilibria on which teams members can potentially coordinate.

Ours is the first experiment we are aware of in which a public goods game with its well-known free rider problem can be converted into a payment for effort environment without free rider problem by the free choices of subjects. It extends the recent innovation of studying institutional evolution in the laboratory, applying it to a key issue in the theory of economic organization that has not previously been addressed by such methods.

Our results are striking. In four of the six treatments with which we experiment, almost all teams are successful at self-monitoring and thus choose not to hire a specialist. But when we make monitoring by team members more costly than that by the specialist, and especially when we switch to a model without a peer monitoring equilibrium, peer monitoring fails in many groups and a trend towards specialist monitoring emerges. Our results thus accord with experimental findings that a large number of subjects attempt cooperation in the lab, but also with the standard experimental finding that in repeated dilemma games without devices such as punishment opportunities or pre-play communication, cooperation tends to flag over time.[1] For this reason, the logic of Alchian and Demsetz's argument is supported in the lab in a particularly clear fashion.

The structure of the paper is as follows. Section 2 briefly discusses the theory and literature on the organizational form of production in a market economy. Section 3 presents our theoretical model, and section 4 lays out its implementation in our experimental design. Sections 5.1 – 5.3 present the experiment's results. Section 5.4 introduces an alternative model with a unique equilibrium of free riding in peer monitoring, and presents results for the corresponding treatment. Section 6 summarizes and provides additional discussion.

[1]See for example Ledyard (1995) and Davis and Holt (1993) for an overview of older public goods experiments, Fehr and Gächter (2000a) for the effect of punishment and Brosig et al. (2003) for the effect of communication.

## 2 Literature

Why most firms in market economies exhibit certain common features, and in particular why control rights usually reside in a group of investor/residual claimants, with employees working under the supervision of their employers, has long been a central question of the economics of organization and comparative institutional analysis. Knight (1921) argued that the more confident and less risk-averse individuals become entrepreneurs while others become workers who demand insurance against risk and who accordingly must be supervised, since their fixed wages give rise to moral hazard (see also Kihlstrom and Laffont (1979)). Alchian and Demsetz's explanation of why workers are supervised by a residual-claiming central monitor was summarized in the introduction. Marglin (1974) argued that capitalists carved out the role of imposing discipline on workers at the expense of workers' welfare, by developing technologies that undercut the positions of independent workers. Holmström (1982) suggested that the monitoring of inputs could be rendered unnecessary by a forcing contract, but the contract envisioned is largely hypothetical and has been argued to suffer from serious moral hazard problems (Eswaran and Kotwal (1984), MacLeod (1988)). Eswaran and Kotwal (1989) and Banerjee and Newman (1993) explain the assignment of control rights to financiers by reference to unequal wealth and imperfections in credit markets associated with the limited liability of borrowers. Kremer (1997) argued that workers usually don't run firms because control by workers leads to a tendency to redistribute earnings among members, which distorts incentives.

Dow and Putterman (2000) and Dow (2003) view Alchian-Demsetz's monitoring hypothesis as one of the leading candidates to explain the conventional employment relationship,[2] alongside theories of worker liquidity constraints and risk aversion, additional financing problems associated with missing membership markets, and potential decision-making problems due to heterogeneity of worker preferences. However, they point out that contrary to the theory's implication that work incentives would be weak without a residual-claiming central monitor, most evidence on worker-owned and profit-sharing firms, as well as that on self-managing teams, suggests that they achieve higher-than-average effort levels with less-than-average numbers of supervisors (Estrin et al. (1987); Weitzman and Kruse (1990); Craig and Pencavel (1995)). Incentives appear to be a strength rather than a weakness of profit-sharing, with a frequently mentioned theme being its encouragement of mutual monitoring.

In a recent experimental study of work organization and incentives Potters et al. (2009) compare laboratory manager-less teams that play a standard

[2]See also the references to Alchian and Demsetz's hypothesis in many of the papers cited in the previous paragraph. One of our referees argued that Alchian and Demsetz's model has no applicability to modern corporations, since in such firms supervision is done by hired personnel and since such personnel could as easily be hired by workers. In fact, Alchian and Demsetz took care to state that their approach is most directly applicable to the "classical capitalist firm" with an owner-manager engaging directly in supervision. They argue, nonetheless, that the corporation system works well partly due to the existence of a market for corporate control in which "control is facilitated by the temporary congealing of share votes into voting blocs owned by one or a few contenders . . . a transient resurgence of the classical firm" (p. 788). A full discussion of the applicability of Alchian and Demsetz's theory to real world firm organization would take us beyond the scope of this paper.

public goods game with teams having managers who can decide how much to pay the other members. They find that managers are able to elicit higher effort from team members than is forthcoming in the PGG, by linking pay to effort somewhat in the manner suggested by Alchian and Demsetz. While the performance of their "managerial" firms is remarkable, their manager-less firms may be a poor representation of self-managing teams, since linkage of pay to effort is ruled out in such teams under their experimental design.

Another attempt to experimentally compare self-managed teams and centrally managed teams has been undertaken by Frohlich et al. (1998). They designed a real-effort experiment wherein they observed higher productivity, greater perceived fairness in pay and lower need of supervisory efforts for employee owned firms compared to the "conventionally owned" firms. Another experimental study incorporating different group incentive mechanisms is Nalbantian and Schotter (1997). They compared revenue sharing, forcing contracts, competition between teams, profit sharing and monitoring. Monitoring in their context was a probability of being observed and getting fired when one's effort is too low. This kind of monitoring was successful but only if the probability is high enough; thus, successful monitoring is expensive.[3]

# 3 A model of team production with monitoring

We model a team consisting of $N$ members who play a finitely repeated game for $T$ periods. In each period, a team member receives an endowment $e$, which we'll assume to be identical for all members. Team member $i$ chooses an amount $c_i$ with $0 \leq c_i \leq e$ to contribute to a team production process, leaving $e - c_i$ for private production. The sum of the team members' contributions (denoted by $C = \sum_{i=1}^{N} c_i$) generates a team profit of $R \cdot C$ with $1 < R < N$. The division of the team profit among the team members depends upon the monitoring technology applied to identify the individual team contributions, which is a result of a simultaneous investment process prior to the contribution decision. Each team member invests $m_i \in [0, \ldots, 1]$ into the monitoring technology at a linear cost $\kappa \cdot m_i$ (with the marginal monitoring cost $\kappa \geq 1$). The total investment in monitoring $M = \sum_{i=1}^{N} m_i$ determines the "accuracy" of the monitoring technology and thus the proportion of the team profit which is divided according to the individual contribution. $M = 0$ allows no identification of the individual contributions and hence the team profit is divided equally among the team members. The higher $M$ is the higher is the proportion of the team profit which is allocated according to the individual contributions. $M = N$ allows a perfect identification of the team members' contributions and hence the team profit is allocated according to the individual contributions. The general rule for team member $i$'s profit is:

$$\pi_i = e - \kappa \cdot m_i - c_i + \frac{N - M}{N} \cdot \frac{R}{N} \cdot C + \frac{M}{N} \cdot R \cdot c_i \qquad (1)$$

[3]The numerous social dilemma experiments beginning with Fehr and Gächter (2000a) or Carpenter et al. (2009), in which subjects can punish those who contribute too little to a public good, can also be viewed as studying alternative incentive mechanisms for group production. In these experiments, the public good always remains public, whereas we allow its public character to be eliminated by monitoring.

The monitoring technology changes the nature of the team problem. Without any monitoring ($M = 0$) team production is a classical linear public good provision problem with free-rider incentives due to $\pi_i = e - c_i + \frac{R}{N} \cdot C$. However, if each team member fully invests in the monitoring technology ($M = N$), team production is a private investment task with $\pi_i = e - \kappa - c_i + R \cdot c_i$. The positive interest rate $R - 1$ provides incentives for full contributions. Intermediate values of $M$ lead to linear combinations of the public and the private good provision. If, for example, half of all team members fully invest in monitoring, i.e. $M = N/2$ , then half of the team output is allocated according to the private contribution and the other half is distributed equally among the team members, i.e. $\pi_i = e - \kappa \cdot m_i - c_i + \frac{1}{2} \cdot \frac{R}{N} \cdot C + \frac{1}{2} \cdot R \cdot c_i$.

Thus, the model reflects Alchian and Demsetz's idea that without monitoring team members have incentives to free-ride on others' effort provision, however with a sufficient investment in monitoring individuals' contributions, team members can be paid according to their contributions as a result of which there will be an incentive to contribute and not to free ride[4]. In the model, the level of monitoring and hence the quality of the pay-effort link is determined and made known before the team members select their production effort, which is necessary if monitoring is to influence effort as Alchian and Demsetz assume it to do.[5] For simplicity, our model compresses the choice of monitoring investment, the observation of effort, and the translation of observations into payment shares into a single step, much as Alchian and Demsetz (p. 778) cover both measurement and apportionment by the term "metering".[6] Hence, team members may choose their effort in response to the remuneration scheme in place, including whether their pay will be linked to their effort, something that might be possible only with monitoring.

For the analysis of the subgame perfect equilibria of the game it is convenient to restructure (1) as:

$$\pi_i = e - \kappa \cdot m_i - c_i + \beta \cdot c_i + \gamma \cdot C_{-i} \tag{2}$$

[4]Notice that the production function in our model is – in contrast to Alchian and Demsetz – additively separable in individual inputs. We decided on this for two reasons: first, to keep the model simple and understandable to the subjects and second that with this kind of production function we can link up to the literature on public good provision, which uses the same kind of modelling. Our set-up nevertheless captures the key Alchian and Demsetz idea that it is socially efficient to contribute to team production, but individual input is not costlessly distinguishable from the inputs of others, unless costly monitoring is provided. Even with a separable production function like the one that we use, individual reward may not be well linked to individual effort without costly monitoring because the inputs of the individual team members might be costly to discern.

[5]The level of supervision or probability of detection of shirking is also assumed known when effort choices are made in efficiency wage models like Shapiro and Stiglitz (1984) and Bowles and Gintis (1990).

[6]In real organizations, there is first a commitment of resources to the monitoring process, then the process itself is carried out as effort is being exerted, and finally the information obtained is used to adjust rewards, including by making promotion and firing decisions. We capture all of this in the simplest possible manner, as a decision on monitoring resources that automatically determines observational accuracy and thereby the degree to which payment follows an equal-sharing versus a proportionate-to-effort formula. Whereas more complex models in which monitoring's accuracy or its translation into payments are stochastic or even subject to intra-organizational conflict (see, e.g. Kremer (1997)) are possible, our model is kept simple so as to focus on the central idea that the members of the team must have a sense of how much monitoring will be in place and how the information obtained is to be used if it is to affect their effort choices.

where $C_{-i} = \sum_{j=1;j\neq i}^{N} c_j$ denotes the sum of the others' contributions, the weight $\beta = \frac{R}{N^2} \cdot (N - M + N \cdot M)$ denotes the team member's individual return from his/her own investment and the weight $\gamma = \frac{R}{N^2} \cdot (N - M)$ denotes the team member's return from the investment of the others.

With no monitoring $\beta = \gamma = \frac{R}{N}$, meaning that all team members profit equally from each unit of contribution, while with perfect monitoring $\beta = R$ and $\gamma = 0$, meaning that only the contributor profits from the own contribution. Obviously, it is individually rational to contribute the entire endowment when $\beta \geq 1$, because each token invested has an individual return of at least 1. $\beta \geq 1$ is satisfied if and only if $M \geq \frac{N}{N-1} \cdot \left(\frac{N}{R} - 1\right) =: \widetilde{M}$.

**Equilibrium investment in monitoring and contributions to the team project**

The game consists of two stages. In the first stage players simultaneously invest in monitoring. After having learned the total investment $M$ players simultaneously decide on their contribution to the team project. We analyze the game by backward induction identifying the subgame perfect equilibria under the assumption that each team member is solely motivated by the maximization of her monetary payoff. Consider the subgames of the contribution to the team project (after the amount $M$ was made public). It suffices to distinguish three classes of subgames: those with $\beta < 1$, those with $\beta > 1$, and those with $\beta = 1$. For $\beta < 1$ the individual return from the individual contribution is lower than the cost of contributing and hence in the equilibria of these subgames all team members choose $c_i = 0$. If, however, $\beta > 1$ each team member individually gains from contributing and hence will choose $c_i = e$ in equilibrium. For $\beta = 1$ players are indifferent between contributing and keeping the entire endowment or parts of it and hence each contribution $0 \leq c_i \leq e$ may be part of a subgame perfect equilibrium. Now turn to the investment in monitoring. The subgame has multiple equilibria. There is a symmetric Nash equilibrium in pure strategies in which no player invests in monitoring ($m_i = 0$) and there is a multiplicity of equlibria in which the critical investment level $\widetilde{M}$ (which is necessary to make full contribution to the public good individually rational) is exactly met. One of these is a symmetric equilibrium in pure strategies in which each player invests the $N$-th part of $\widetilde{M}$ (i.e. $m_i = \frac{\widetilde{M}}{N}$). In addition, there is an infinite number of asymmetric pure strategy equilibria of the subgame which are all characterized by investments $m_i$ satisfying $M = \widetilde{M}$ and additionally there are symmetric and asymmetric mixed strategy equilibria.

Hence the "good news" that the public good dilemma of team production may be "resolved" in the monitoring phase prior to it comes along with the "bad news" that the investment in monitoring is vulnerable to severe coordination failures due to a multiplicity of equilibria.[7]

**Specialists monitoring**

To overcome the problem of multiple equilibria in the monitoring phase, team members may hire a specialist to take the monitoring decision. The substitution of peer monitoring by specialist monitoring has the advantage that the

[7]See also Marx and Matthews (2000).

specialist is a single decision maker who (in equilibrium) chooses an incentive compatible level of monitoring without any coordination problems. The drawback is that she has to be paid a share of the team output in order to have the proper incentives.[8]

Let the specialist be entitled to a share $S \leq 1$ of the team profit $R \cdot C$. Suppose that the specialist has an endowment $e_S$ which enables her to invest at least $\widetilde{M}$ units of monitoring. Thus, the payoff functions under specialist monitoring are as follows:

$$\pi_S = \quad e_S - \kappa_S \cdot m_S + S \cdot C \cdot R \qquad \text{for the specialist} \tag{3}$$
$$\pi_i^S = \quad e - c_i + \beta^S \cdot c_i + \gamma^S \cdot C_{-i} \quad \text{for team member } i \tag{4}$$

with the adjusted weight $\beta^S = (1 - S) \cdot \beta$ denoting the team member's individual return from the own investment after deduction of the specialist's share and the adjusted weight $\gamma^S = (1 - S) \cdot \gamma$ denoting the team member's return from the investment of the others after deduction of the specialist's share.

Full contribution of the team members is individually rational if and only if

$$\beta^S \geq 1 \Leftrightarrow M \geq \frac{N}{N-1} \cdot \left( \frac{N}{(1-S) \cdot R} - 1 \right) =: \widetilde{M}^S. \tag{5}$$

If the specialist invests less than $\widetilde{M}^S$, team members in equilibrium contribute a total of 0 units of effort to team production, so the specialist's earnings from team production will be $S \cdot 0 = 0$. If the specialist invests at least $\widetilde{M}^S$ in monitoring, each team member in equilibrium contributes his/her full endowment of e to team production, so the specialist's earnings from team production will be $S \cdot N \cdot e \cdot R$. Hence, for reasonable costs $\kappa_S$ the specialist will in equilibrium choose the lowest monitoring level for which it is individually rational for the team members to fully contribute their endowment – that is $\widetilde{M}^S$ – and gain a total profit of $\pi_S = e_S - \kappa_S \cdot \widetilde{M}^S + S \cdot N \cdot e \cdot R > e_S$.

To recap, we presented a formal model of team production in the spirit of Alchian and Demsetz. The elegance of the model is that it allows a continuous transformation of the team problem with free-riding incentives into a profitable private investment prob- lem through the actions of the team members and/or the decision of the specialist monitor. Due to the multiplicity of equilibria, it is difficult – though not impossible – that team members manage the transformation on their own. In contrast, the specialist is unambiguously predicted to carry out the transformation if parameters are consistent with $\pi_S > e_S$ when $M = \widetilde{M}^S$, since she can accomplish this by a single individual decision. The drawback to the team members of hiring is its cost, albeit it is – in equilibrium – more than compensated compared to full free-riding.

[8] Alchian and Demsetz never spell out where the residual earnings of the central monitor come from, simply asserting that the monitor pays team members the estimated value of their marginal products and keeps the residual. Our model assigns to the monitor a fraction of the output because with average and marginal product equal, there is no residual above the sum of marginal products. We implement the model with sufficiently large $R$ so that both monitor and team members can profit from centrally monitored team production.

**A discrete version of the model**

For the experimental implementation of the game we chose a discrete version of the payoff function and a binary choice in the investment in peer monitoring $m_i \in \{0, 1\}$ to facilitate comprehension by subjects. We exogenously introduce two different thresholds of monitoring $T_1$ and $T_2$ with $T_1 < T_2 \leq N$. If the total investment in monitoring $M < T_1$ all team members equally profit from all contributions, for $T_1 \leq M < T_2$ half of the team profit is allocated equally and the other half according to individual contributions, and finally, for $T_2 \leq M \leq N$ each team member solely profits from his/her own contribution. Notice, that players are informed both on the achieved monitoring threshold (but not on the exact value of $M$) and on the corresponding payoff function:

$$\pi_i = \begin{cases} e - \kappa \cdot m_i - c_i + \frac{1}{N} \cdot R \cdot C, & 0 \leq M < T_1 \\ e - \kappa \cdot m_i - c_i + \frac{1}{2} \cdot \frac{1}{N} \cdot R \cdot C + \frac{1}{2} \cdot R \cdot c_i, & T_1 \leq M < T_2 \\ e - \kappa \cdot m_i - c_i + R \cdot c_i, & T_2 \leq M \leq N \end{cases} \tag{6}$$

In terms of $\beta$ and $\gamma$ this means:

$$\begin{cases} \beta = R/N, & \gamma = R/N & 0 \leq M < T_1 \\ \beta = \frac{R(N+1)}{2N}, & \gamma = \frac{R}{2N} & T_1 \leq M < T_2 \\ \beta = R, & \gamma = 0 & T_2 \leq M < N \end{cases}$$

**Example**

The following example illustrates the model and uses functional forms and parameters that will also be used in our experiment. Let $N = 5$ be the number of team members with an endowment $e = 10$, marginal monitoring costs $\kappa = \kappa_S = 1$, a multiplier $R = 3$, the specialist's endowment $e_S = 5$ and the specialist's share S = 0.25. Then

$$\begin{cases} \beta = 0.6, & \gamma = 0.6, & \beta^S = 0.45, & \gamma^S = 0.45 & 0 \leq M < T_1 \\ \beta = 1.8, & \gamma = 1.5, & \beta^S = 1.35, & \gamma^S = 1.125 & T_1 \leq M < T_2 \\ \beta = 3.0, & \gamma = 0, & \beta^S = 2.25, & \gamma^S = 0 & T_2 \leq M < N \end{cases}$$

Hence for $M \geq T_1$ full contribution to the team project is individually rational, because the individual return from investment $\beta$ is greater than 1. In the subgame perfect equilibrium without peer monitoring $(m_i^* = 0)$, contributions to the team project are 0 $(c_i^* = 0)$, leading to team members' payoffs of 10. However, there are also equilibria in which monitoring takes place. The simplification of the model by choosing discrete values of monitoring and thresholds restricts the number of those equilibria. Nevertheless, there are still $\binom{N}{T_1}$ subgame perfect pure strategy equilibria, characterized by exactly $T_1$ team members investing in monitoring in addition to mixed strategy equilibria (see below).

In the experiment we used two treatments in which $T_1 = 2$ and three in which $T_1 = 4$. Because team members are restricted to integer investments, a symmetric equilibrium with monitoring is not achievable. This means that the only symmetric pure strategy equilibrium prescribes no investment in peer monitoring. All the pure strategy equilibria with monitoring are asymmetric and hence very vulnerable to coordination failure. In case of $N = 5$ and $T_1 = 2$,

Table 1: Symmetric mixed strategy equilibria

| **Parameterization** | **Probability of investment in monitoring in "low probability" equilibrium** | **"high probability" equilibrium** |
|---|---|---|
| $T_1 = 2, T_2 = 5, \kappa = 1$ | 0.0130 | 0.7439 |
| $T_1 = 4, T_2 = 5, \kappa = 1$ | 0.2561 | 0.9870 |
| $T_1 = 4, T_2 = 5, \kappa = 3$ | 0.3960 | 0.9572 |

the game has 10 pure strategy equilibria in which exactly 2 out of the 5 players have to invest in monitoring and in case of $N = 5$ and $T_1 = 4$, the game has 5 pure strategy equilibria in which exactly 4 out of the 5 players have to invest in monitoring.

In a symmetric mixed strategy equilibrium each player has to be indifferent between investing and not investing in monitoring, which means that the expected excess gain from investing in monitoring has to equal the cost of investing in monitoring. To achieve this, each team member assesses the probability that he/she is pivotal, meaning that by his/her investment in monitoring the threshold to incentive compatible contributions would be reached.[9] Only in the case of being pivotal, a player may have an incentive to invest in monitoring. Appendix A provides the exact calculations for the symmetric mixed strategy equilibrium. In fact, it can be shown that in our parameterization there are two symmetric mixed strategy equilibria in each of the parameterizations, one with a low probability of investment in monitoring and another one with a high probability of investment in monitoring, as listed in table 1. For each of the three parameterizations the table lists the probability of investing in monitoring in each of both equilibria. In the first parameterization, for example, each player independently chooses to invest in monitoring with probability of 1.3% in the low probability equilibrium, whereas each player independently chooses to invest in monitoring with roughly 75% probability in the high probability equilibrium. These numbers allow us to calculate the likelihood with which we can expect the different investment levels if subjects are playing the respective equilibrium strategies. In figure 3 we will report these numbers and contrast them to the observed frequencies.

If team members are able to self-organize (i.e. achieve $M \geq T_1$) each team member earns 30 minus the investment in monitoring (if individually applicable).[10] In the equilibrium of specialist monitoring the specialist invests $T_1$ in monitoring and the team members contribute their entire endowment. Hence, the team members earn $22.5 = 0.75 \cdot 30$ and the specialist earns her endowment (of 5) minus the monitoring investment plus $37.5 = 0.25 \cdot 150$.

Obviously, it would be most profitable for the team members to play one of the equilibria with positive peer-monitoring. Then each member earns 29 or 30, dependent on whether he/she invested in monitoring or not. However, failing to reach the sufficient level of monitoring leads to drastically lower individual payoffs of 9 and 10, dependent on whether the individual invested

[9] See also Gradstein and Nitzan (1990) and Offerman et al. (1996).

[10] Notice that the monitoring cost is paid out of end-of-round earnings; thus, contributing to monitoring doesn't prevent a subject from still contributing a full 10 units to team production.

Table 2: Symmetric mixed strategy equilibria

| **Division rule** | **Step Structure 2-5** | **Step Structure 4-5** |
|---|---|---|
| equal division ("EQUAL") | $0 \leq M < 2$ | $0 \leq M < 4$ |
| half divided equally, half according to contributions ("HALF/HALF") | $2 \leq M < 5$ | $4 \leq M < 5$ |
| Division according to individual contributions ("ATIC") | $M = 5$ | $M = 5$ |

in monitoring or not.[11] Facing this risk, team members may decide to hire a specialist to make the monitoring decision and achieve a payoff 7.5 lower than the highest equilibrium payoff, but 13.5 higher than the worst payoff in case of coordination failure without sufficient monitoring.

# 4 Experimental design

We conducted an experiment consisting of five treatments corresponding closely to the model above. In each session of the experiment, subjects were randomly and anonymously assigned to groups of six, with one subject randomly assigned the role dubbed "observer" (corresponding to the theory section's "specialist") and the other five the role "team member". We implemented the discrete version of the game described above with the parameters of the example above. Subjects were told at the outset that they would engage in thirty rounds of decisions in the same roles and with the same anonymous group members. The two *step structures* 2-5 ($T_1 = 2$ and $T_2 = 5$) and 4-5 ($T_1 = 4$ and $T_2 = 5$) specify two sets of parameters for the thresholds $T_1$ and $T_2$, which in turn generate three possible incentive regimes for team production henceforth referred to as EQUAL, HALF/HALF, and ATIC ("according to individual contribution") (see table 2).

In step structure 2-5 at least two units have to be invested in monitoring to make contributions to the team project individually rational, while in step structure 4-5 at least 4 units have to be invested. Each group of subjects was assigned to either one structure or the other throughout their session, with no knowledge of the other structure.

The 30 rounds of a session were divided into six phases, with 5 rounds each. In every session, Phase I consisted of 5 rounds with no monitoring – i.e., a standard 5 round VCM condition. Phases II and III consisted of 5 rounds with monitoring (if any) by the observer and 5 rounds of monitoring (if any) by peers, with the order in which observer and peer monitoring occurred varying among sessions (see table 3). In OP sessions, the observer made the monitoring decisions in Phase II and the team members made the monitoring decisions in Phase III; in PO sessions, the order was reversed.

[11] The other form of coordination failure in the form of over-provision of monitoring is "less disastrous" because it just leads to more players earning 29 instead of 30, than in equilibrium.

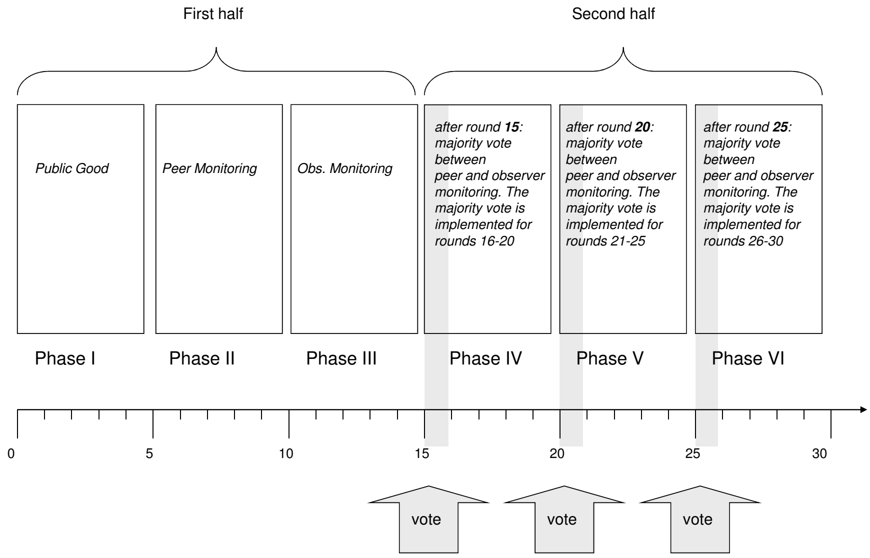


Figure 1: Schematic representation of the course of the interaction for PO

To avoid boredom and unnecessary inequalities and to motivate the observer to learn about incentives in team production, we assigned the observer a task to perform in those periods in which he or she was not permitted to monitor and earn a 25% share of team project revenue. The observer's task was to estimate the period's sum of contributions $C$ in his/her group. As an incentive for accuracy, the observer earned more the closer was his/her guess to the actual $C$, which was revealed to him/her at the end of the period.[12] Note that the observer might learn something about how team members' contributions respond to monitoring by observing peer monitoring phases, and accordingly sessions using the PO ordering might be expected to be more conducive than those with ordering OP to successful decision-making by the observer when in the monitoring role.

In each session, each of the last three phases could have either observer or peer monitoring, depending on how the members of the team in question voted. Before rounds 16, 21, and 26, each team member was asked to vote for either observer or peer monitoring. The group was informed of the majority vote (without a breakdown of the number of votes) and began to play five rounds according to the chosen institution. A schematic representation of the course of the interaction in the PO ordering is given in figure 1. Phases I to III form the first half of the experiment, and phases IV to VI the second half.

The alternatives of the PO or OP ordering and of the 2-5 or 4-5 monitoring structure give rise to a 2x2 design with four treatments: PO25, OP25, PO45, OP45. Due to the unexpected nature of the results of those treatments, which

[12]The formula for the observer's profit during phases in which he did not play a monitoring role, such as Phase I, was: $\pi = \frac{30}{1+0.05|C-Guess\ of\ C|}$

Table 3: Treatment description

| Treatment | Phase Sequence | | Step | Monitoring unit cost | |
|---|---|---|---|---|---|
| | Phase II | Phase III | strc. | Peer $\kappa$ | Observer $\kappa_S$ |
| PO25MC1 | Peer | Observer | 2-5 | 1 | 1 |
| OP25MC1 | Observer | Peer | 2-5 | 1 | 1 |
| PO45MC1 | Peer | Observer | 4-5 | 1 | 1 |
| OP45MC1 | Observer | Peer | 4-5 | 1 | 1 |
| PO45MC3 | Peer | Observer | 4-5 | 3 | 1 |

are discussed in the next section, we conducted sessions with an additional treatment that is otherwise like the OP45 treatment but in which the marginal cost of monitoring was made three times higher for a team member than in the other four treatments, while the cost of monitoring for the observer was left unchanged (i.e. $\kappa = 3$ and $\kappa_S = 1$). We distinguish the two treatments by referring to them as OP45MC1 and OP45MC3, with the other three treatments also sharing the MC1 designation. Table 3 provides an overview of the five treatments.

In each treatment we have 6 groups (from two sessions of three groups each) each containing 6 subjects (5 team members and 1 observer). Hence we had 180 subjects in the experiment who were randomly allocated to the different treatments. Each subject sat in a separate compartment in the experimental lab at the University of Erfurt and interacted anonymously via the computer interface with the other subjects in his/her group. The identities of the other group members were not revealed and could not be deduced, because three groups were playing in parallel. There was no possibility of verbal communication with others; the only information transmitted was on the actual choices. Subjects were first read aloud and followed on their screens instructions explaining the structure of the entire session, worked through examples, and asked the experimenter questions, if any. The instructions are provided in appendices C and D.[13] The subjects were students who were recruited at the University of Erfurt using the Orsee System[14]. The experiment was conducted with the z-tree Software package (Fischbacher, 2007). Subjects were paid privately after the end of the experimental session with an exchange rate of EUR 3 for each 100 experimental currency units. They earned on average EUR 21.

# 5 Results

Evaluation of the data shows that there are no significant effects associated with whether the OP or the PO order is used in phases II and III, in particular the investments in monitoring and the contribution levels are not significantly different.[15] Therefore, we analyze the pooled treatments PO25MC1 and

[13]See also http://data.cereb.eu/monitoring.html for additional materials including the tables used to show payoffs in the treatment discussed in section 5.4.

[14]http://www.orsee.org/

[15]The difference in average contributions and monitoring between OP and PO are not different at 10% level (exact Mann-Whitney-U-Test over the independent observations, two-sided) with one

OP25MC1 as 25MC1 and the pooled treatments PO45MC1 and OP45MC1 as 45MC1. In each of the pooled treatments we now have 12 independent observations. Discussion of treatment PO45MC3 is postponed to section 5.3.

## 5.1 Effects of monitoring in the first half

The results of the first phase of play, in which subjects interact in a classical public goods environment, are well in line with the observations from numerous previous experimental studies of VCMs. Average contributions start off at about half of the endowment – 5.5 on average over all groups – and decrease from there on. In all four treatments we observe a negative trend in contributions over time[16] with an average contribution of 3 in the last period of Phase I. This deterioration of contributions is in line with past experiments[17] and illustrates Alchian and Demsetz's intuition about free riding if monitoring is absent, yet departs (as is typical in VCMs) from the strict theoretical prediction of zero contributions assuming payoff-maximizing agents.

*Which division rules were implemented?* Peers managed to supply incentive-imparting division rules 95% of the pooled cases of the two treatments, while the observers did so in 82.5% (see figure 2a)).[18]

**Result 1.** *Failure to achieve a division rule providing incentives to contribute the full endowment occurred less often in the peer than in the observer monitoring phases of the first half.*

At first glance, it comes as a surprise that despite their coordination problem team members succeeded more often in achieving an incentive compatible allocation rule than observers. But high "success rates" as observed in our experiment are well in line with observations in binary step-level/threshold public good experiments:[19] van de Kragt et al. (1983) for example observed a 72% rate in the treatment with a step-return[20] like our 45MC1 treatment. Offerman et al. (1996) observed lower success-rates with step returns quite similar to 25MC1 and 45MC1. The observation of Croson and Marks (2000) that subjects respond to the size of the step-return may explain the difference in the success rates of 25MC1 and 45MC1.

*How did the teams manage the high investments in monitoring?* The only symmetric equilibria with positive investments in monitoring are the two mixed

exception: OP25MC1 vs. PO25MC1 is significantly different in the monitoring investments of the observer in the observer monitoring phase ($p = 0.0065$), but has no significant effect in contributions. The average monitoring was 2.2 in PO25MC1 and 3.4 in OP25MC1.

[16] A linear regression shows a negative time trend in contributions for Phase I. The regression is performed with the average (per group) contributions of Phase I as the dependent variable. The time coefficient is significantly negative with at least 5% for all treatments (robust, Huber-White standard errors).

[17] See again Ledyard (1995) as well as Davis and Holt (1993) for a review of the literature on VCM experiments.

[18] This difference is significant ($p = 0.044$, two-sided exact Wilcoxon signed rank test over the independent observations).

[19] See Croson and Marks (2000) for a review.

[20] The step return is a concept analyzed in Croson and Marks (2000). The step return is the fraction of the aggregated group payoff over the total contribution threshold (step return = aggregated group payoff/ total contribution threshold). Assuming the subjects would fully contribute in HALF/HALF we would have a step-return of 10 in 25MC1 and a step-return of 5 in 45MC1.

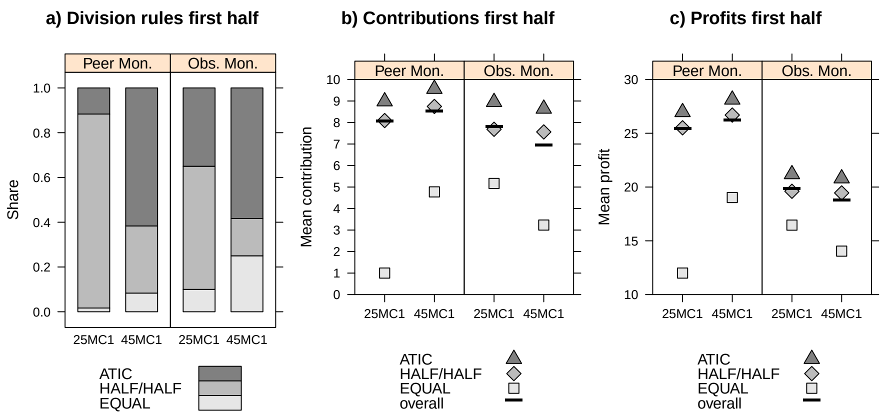


Figure 2: **a)** Frequency of implemented division rules; displayed are averages over the observations in the peer and observer monitoring phases of the first half in the 25MC1 and 45MC1 treatments. **b)** Average contributions over the observations in the peer and observer monitoring phases of the first half in the 25MC1 and 45MC1 treatments. **c)** Average team member payoffs in the peer and observer monitoring phases of the first half in the 25MC1 and 45MC1 treatments. The team member payoffs are net payoffs, meaning that the individual team member's monitoring costs are already deducted in the peer monitoring phase and the observer's share is deducted in the observer monitoring phase.

strategy equilibria (see table 1). Figure 3 shows the distributions of total monitoring investments $M$ in each of both symmetric mixed strategy equilibria and the actually observed distribution, for each of the three parameterizations in the first as well as in the second half.

In each of the six cases, displayed in figure 3, the generalized Fisher exact test rejects the hypotheses that the observed distribution coincides with the equilibrium distribution at p=0.0001 for the low probability equilibrium as well as for the high probability equilibrium. The low probability equilibrium rarely meets the threshold, while the high probability equilibrium leads to frequent overprovision. The team members seem to be better in "managing" the provision problem, because they meet the threshold more frequently than in the low probability equilibrium, avoiding overprovision more often than in the high probability equilibrium.[21] Although team members do not seem to play one of the symmetric mixed strategy equilibria (an observation that is shared with Offerman et al. (1998)), we cannot definitely exclude that they play an asymmetric mixed strategy equilibrium. The frequencies displayed in figure 3 also show that team members do not play any asymmetric pure strategy equilibrium, because then they would meet the threshold (2 and 4, respectively) and neither over- nor under-provide in monitoring.

A possible explanation of the observed behavior is that a certain fraction of subjects is guided by "non-standard" or social preferences, for example, that

[21] The theoretically expected overprovision is 89.0% for 25MC1, 93.7% for 45MC1 and 80.4% for 45MC3 in the high probability equilibrium, whereas we observe levels of 86.7% (25MC1), 61.7% (45MC1) and 26.7% (45MC3), respectively.

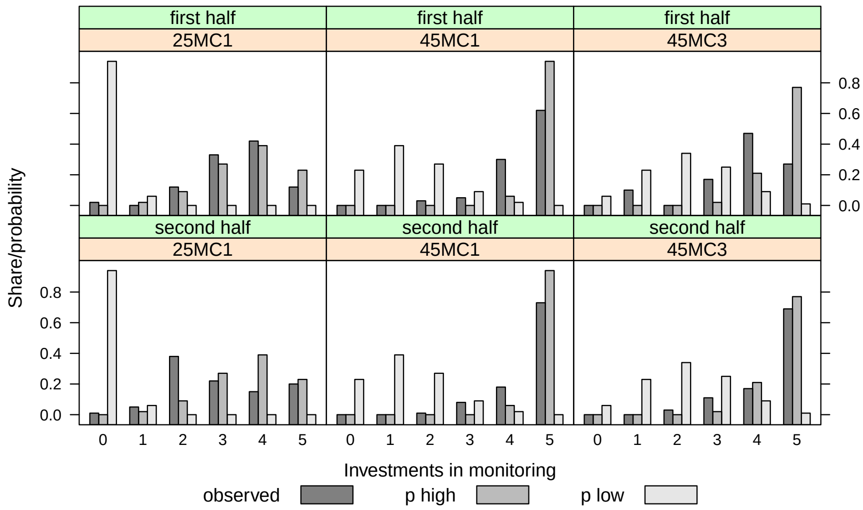


Figure 3: Distributions of total peer monitoring investments $M$ in each of both symmetric mixed strategy equilibria and the actually observed distribution, for each of the three parameterizations in the first as well as in the second half.

some subjects are conditional cooperator[22] for whom the (subjective) payoffs in a VCM may resemble those of an assurance or stag hunt game more than those of a prisoners' dilemma. Their presence could help to explain the higher-than-predicted contributions in Phase I, and likewise would account for propensities to contribute to monitoring even if coordination is difficult or if no equilibrium strategies existed, for payoff-maximizers.[23] Evidence that subjects with preference-based inclinations to cooperate account both for some contributions and some monitoring could be found in a significant correlation between contributions especially in the first period of Phase I, and average monitoring during a peer monitoring phase. We checked the correlation at individual subject level between monitoring investment during the exogenous peer monitoring phase and first period contribution in Phase I. Pooling the data for the two MC1 treatments, we found a significant positive correlation, meaning that the subjects with high contributions also tend to invest in monitoring (asymptotic Spearman correlation test, stratified by treatment, $p = 0.016$).

*How did subjects' contributions respond to the various division rules?* With peer monitoring (in Phase II) and observer monitoring (in Phase III), subjects responded to HALF/HALF and ATIC division rules with a considerable increase in average contributions compared to EQUAL division as can be seen in figure

[22]In the sense of Fehr and Gächter (2000b) and Fischbacher et al. (2001)

[23]Duffy et al. (2007) find that subjects are not much more likely to complete a public project of fixed size when a final payoff jump causes equilibrium strategies in positive contributions to exist than when absence of such a jump makes a positive giving equilibrium theoretically non-existent, a result that might also be explained by the presence of some conditional willingness to cooperate. Nevertheless, the presence of a payoff jump in this section's linear design but its absence in our later QUAD treatment (see section 5.4, below) may explain some of the difference between behaviours in these treatments.

2b).[24] A comparison of HALF/HALF and ATIC exhibits two mild surprises: First, subjects contributed moderately but significantly[25] more under ATIC than under HALF/HALF. This is remarkable because a payoff-maximizing subject should contribute her full endowment under both division rules (recall that in both cases one unit of contribution is repaid by more than one, for all possible actions of the other team members). Two explanations, both invoking bounded rationality, come to mind. Firstly, although under both schemes each unit of contribution is repaid by more than 1, the private marginal return under HALF/HALF is just 1.8 while it is 3.0 under ATIC. The difference in contributions may be explained by subjects' concern for marginal returns[26] and/or social preferences. Under ATIC only the contributing team member profits from her contribution, whereas under HALF/HALF all other team members also profit (at least partly). Although it maximizes the individual payoff, a team member may (for example, due to fairness concerns) withhold contribution in order to reduce a potential free-rider's benefit from her contributions. The second surprise in comparing HALF/HALF and ATIC is that subjects tend to contribute somewhat less when the observer monitored than when the team members do.[27] Both explanations offered above – i.e. the sensitivity to differences in MPCRs, although exceeding 1, and fairness considerations – may also be valid to explain this phenomenon.

**Result 2.** *Contributions in Phase I (EQUAL division) are consistent with those in the experimental literature on the voluntary contribution mechanism. In Phases II and III, contributions are higher under ATIC than under HALF/ HALF and – ceteris paribus – contributions are higher under peer than under observer monitoring.*

In light of result 2 and the higher costs under observer monitoring, it comes as no surprise that team members' earnings were significantly lower under observer monitoring than under peer monitoring.[28]

**Result 3.** *Team members' earn less under observer monitoring than under peer monitoring.*

## 5.2 Voting results and consequences

One of our main research focuses is on the endogenous monitoring choice after subjects gained experience with peer as well as with observer monitoring. The voting results draw a very clear picture: the observer was never chosen by majority vote in the 36 voting rounds of treatment 45MC1 and chosen only once in the same number of votes in treatment 25MC1 (see table 4). The experience from the first half of successful peer monitoring at higher payoffs may well explain why team members voted to implement peer rather than observer monitoring in the second half of their sessions. Of course, if teams had then

[24] For observer monitoring contributions under EQUAL differ significantly from the ones of HALF/HALF ($p = 0.023$ two-sided exact Wilcoxon signed-rank test, 25MC1 and 45MC1 pooled). For peer monitoring there are too few occurrences of the EQUAL rule for a meaningful test.

[25] The difference is significant in both phases (Phase II: $p = 0.006$ and Phase III: $p = 0.006$, both according to the two-sided exact Wilcoxon signed-rank test).

[26] See also Isaac and Walker (1988a).

[27] The difference is significant for HALF/HALF ($p = 0.074$) as well as for ATIC ($p = 0.025$), both according to the two sided exact Wilcoxon signed-rank test.

[28] $p < 0.01$, two-tailed Mann-Whitney-U-test over the independent observations

Table 4: Choice of Observer or Peer Monitoring in the second half

| | Number of choices of | |
|---|---|---|
| | **Observer monitoring** | **Peer monitoring** |
| 25MC1 | 1 (3%) | 35 (97%) |
| 45MC1 | 0 (0%) | 36 (100%) |

failed to achieve sufficient monitoring to sustain contributions in later phases, they might be expected to have switched to voting for observer monitoring (see section 6). But no team experienced more than one period of incentive failure during phases IV and V, so their ongoing preference for peer monitoring is not surprising.[29]

**Result 4.** *In the four MC1 treatments, the observer is almost never chosen by the majority vote of the team members.*

*How did the teams voting for peer monitoring perform?* In the majority of cases team members failed to reach the exact level of monitoring necessary to provide incentives for full contributions. In 25MC1 an investment in monitoring of exactly 2 was reached in 37.7% of the cases, while in 45MC1 the equilibrium level of exactly 4 units of monitoring was only reached in 18.3% of all cases. This demonstrated the high vulnerability of monitoring to coordination failure. Nevertheless, as in the first half of the experiment in the two MC1 treatments the peer monitored groups were very successful in implementing a division rule in which full contribution to the team project is individually rational (see figure 4a)). They implemented HALF/HALF or ATIC in 93% of the cases, either by providing the exact level of investment necessary to give incentives for full contribution or by over-investment (compared to the equilibrium prediction). Figures 4b) and 4c) additionally show that contributions as well as payoffs under both sharing rules are extremely high. However, we still observe the interesting difference between HALF/HALF and ATIC: contributions under ATIC are on average 9.9, whereas contributions under HALF/HALF are on average 8.7. The difference is significant[30].

**Result 5.** *In the MC1 treatments peer monitoring performs extremely well: in 93% of the cases a rule capable of eliciting full contributions is reached; contributions are near 100% of endowments and payoffs are high.*

An interesting finding is that the average payoffs in 45MC1 are weakly significantly higher than in 25MC1[31], although 4 instead of 2 units of monitoring are required to make full contribution individually rational. The reason is the extremely high number of implementations of ATIC in 45MC1 accompanied

[29]We can find no explanation for the one instance in which three of five team members voted for observer monitoring after Phase IV, occurring in OP25MC1. Although the team in question had achieved HALF/HALF monitoring in four of five periods of Phase II with a bare two subjects monitoring (achieving ATIC one time), team members have no way to know whether 2, 3 or 4 monitored, and their earnings were higher under peer (Phase II) than observer (Phase III) monitoring in every period. Non-parametric tests for differences between the antecedents of that vote and others in the MC1 treatments are impossible since the case in question is singular.

[30]$p < 0.001$, two tailed exact Wilcoxon test conducted over the independent observations

[31]$p = 0.043$ one sided Mann-Whitney U test conducted over the independent observations

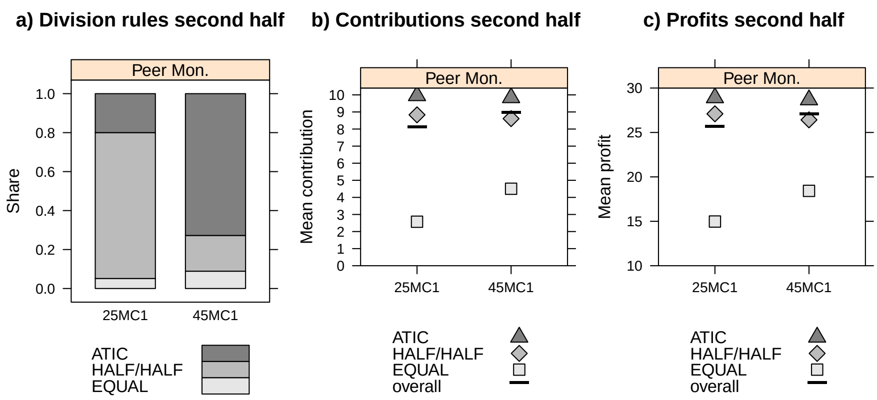


Figure 4: **a)** Frequency of implemented division rules; **b)** Contributions; **c)** Payoffs (incl. monitoring costs); displayed are averages over the observations in the second half

by high contributions in ATIC (see above). A likely reason is that by "overinvestment" in monitoring the risk of coordination failure is reduced at a low cost. Given the lack of verbal communication it seems practically impossible to play an asymmetric equilibrium. Thus, most team members seem to have decided to monitor every period. Not only is the average cost of over-monitoring to each subject (statistically speaking) only one unit every five periods, but in practice that cost is not "wasted", given that subjects respond to ATIC with more effort than to HALF/HALF. The histograms of the total investment $M$ in figure 3 show systematic "overinvestment" in monitoring.

## 5.3 Raising the bar – a further test

As we have seen, in sections 5.1 and 5.2 team members seem to reduce the risk of coordination failure by "overinvestment" in monitoring, which is a less costly way of achieving an incentive compatible division rule than "hiring" the observer. In the light of these results we extended our analysis by conducting a new treatment PO45MC3 which is identical to PO45MC1, with the only exception that for the peers the cost of one unit of monitoring is raised to 3 (i.e. $\kappa = 3$). This raises the bar for peer monitoring: it increases the cost of implementing the HALF/HALF rule from 4 to 12, triples the cost for implementing ATIC from 5 to 15, and it also triples the cost to the individual of adhering to an "overinvestment" strategy.[32] Notice that the observer's cost remains at 1 per unit of monitoring (i.e. $\kappa_S = 1$). We collected six independent observations in this treatment. Through this change monitoring by the observer should become more attractive.

[32] As before, the monitoring charge is still paid out of end-of-round earnings, so it is possible to pay 3 to monitor, yet still contribute 10 to team production.

**Voting results and consequences**

Indeed, we observe a sharp increase in voting results implementing observer monitoring. The observer was voted for by a majority in 61% of the 18 votes. Figure 5a) shows that the observer implements ATIC in the majority of cases. In response to this, team members make high contributions and receive payoffs which are diluted by the observer's share of 25%. Interestingly, in those groups and phases in which peer monitoring was the voting choice, team members manage to achieve HALF/HALF or ATIC in almost 90% of periods. Hence, when peer monitoring is voted by the majority of the team, the team is quite successful in providing enough units of monitoring to provide incentives for making full contributions individually rational, despite the higher costs and continued, perhaps even exacerbated, coordination problem.

What is it that makes the observer model more appealing to subjects in PO45MC3? Figures 5 shows the differences in the first half between those groups voting for the observer later on (vote O) and those who did not (vote P). It is clear from figure 5a that there were more failures to achieve HALF/HALF or ATIC under exogenous peer (observer) monitoring, in groups that eventually voted for observer (peer) monitoring. Those groups which vote for peer monitoring experienced higher average contributions under peer monitoring in the first phase, while those who vote for observer monitoring experienced higher contributions under observer monitoring in the first phase (see figure 5b). The same tendency is observed when looking at profits (see figure 5c).

**Result 6.** *If the unit cost of peer monitoring is raised to 3, the majority of teams vote for observer monitoring. However, almost 40% still vote for peer monitoring and perform well, out-earning those who hire the observer.*

## 5.4 Extending the model: The zero monitoring equilibrium case

In our model presented so far equilibria with a positive level of monitoring exist. We wondered whether the tendency of team members to pay for monitoring – despite the temptation to let others do the job – would survive a still harder challenge: a situation in which the only equilibrium in monitoring involves no monitoring at all. To model peer monitoring as a pure public good problem, we need a specification in which the gains from monitoring lack the discrete jump that can make the marginal unit privately profitable. We achieve this by introducing a quadratic cost function in production.[33] Specifically, we change the profit function for a team member in the peer monitoring phase to

$$\pi_i = e - \kappa \cdot m_i - \frac{c_i^2}{f} + \beta \cdot c_i + \gamma \cdot C_{-i}. \tag{7}$$

where $f$ is a cost function parameter. As a second change, we eliminate the step-like relationship between payoffs and monitoring, now allowing $\beta$ and $\gamma$ to increase and decrease, respectively with each unit by which $M$ rises or

[33] Quadratic cost functions in the context of public good experiments were used for example in Isaac and Walker (1988b), Irlenbusch and Ruchala (2008), Keser (1996), Sefton and Steinberg (1996).

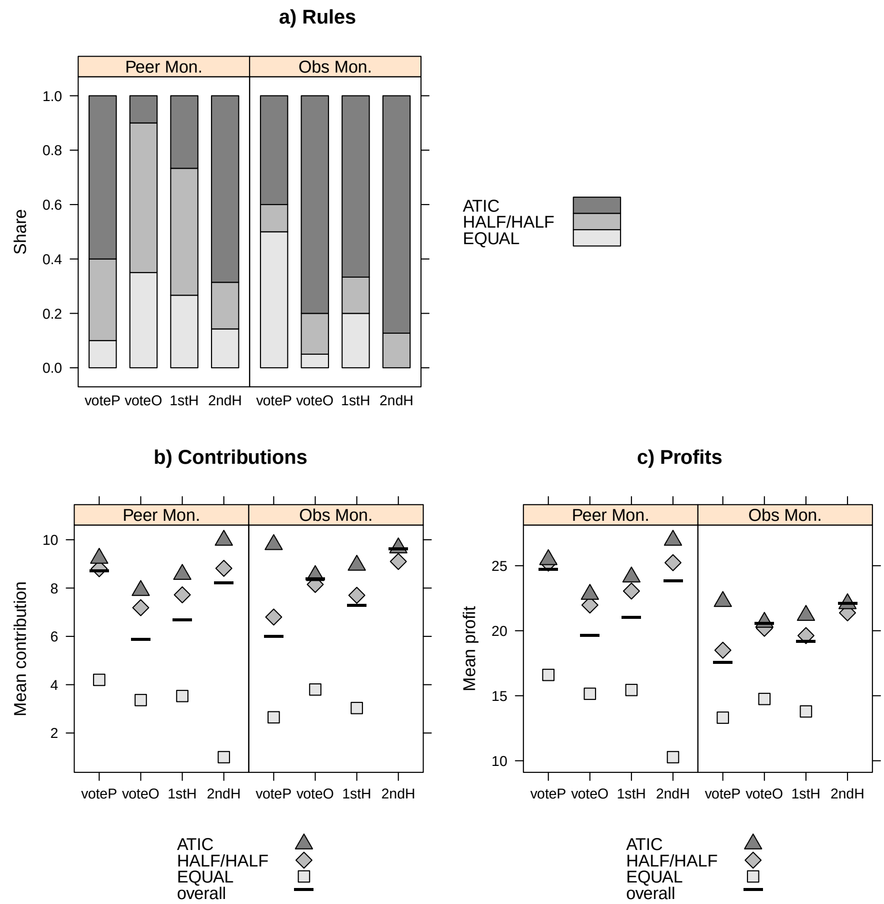


Figure 5: **a)** Frequency of implemented division rules; displayed are averages over the observations in the first half of PO45MC3 comparing those groups voting for the observer (vote O) with those who voted for peer monitoring (vote P), the overall share of the rules in the first half (1st H) and the second half (2nd H). **b)** and **c)** averages of the contributions resp. profits over the first half of those groups voting later for the peer monitoring (vote P) or observer monitoring (vote O) plus the averages of the first and second half without the voting decision distinction.

declines.[34] During the observer monitoring regime the $\beta$ and the $\gamma$ in equation (7) are replaced by their by $(1-S)$ reduced counterparts $\beta^S$ and $\gamma^S$. Again, the investment decision $m_i$ is binary.

The individual optimal contribution for the peer monitoring mechanism with the new model is

$$c_i^*(M) = \frac{f}{2} \cdot \frac{N + M(N-1)}{N^2} R = \frac{f}{2}\beta. \tag{8}$$

Since the monitoring decision of each subject is binary, profit-maximizing peers will never invest in monitoring as long as the profit difference $\Delta\pi_{\text{invest}}$ between investing in monitoring and not investing in monitoring is at most zero. Let $M_0$ be the arbitrary but fixed monitoring level of the other group members. Then the profit surplus from monitoring is:

$$\begin{aligned} \Delta\pi_{\text{invest}} &= \pi\left(c_i^*(M_0+1)\right) - \pi\left(c_i^*(M_0)\right) \\ &= -\kappa + \frac{fR^2(N-1)^2(2N-1)}{4N^4} - \frac{fR^2(N-1)^2}{2N^4} M_0 \end{aligned} \tag{9}$$

If, as in our parameterization of the game, $\Delta\pi_{\text{invest}} \leq 0$, no team member invests in monitoring (i.e. $M^* = 0$ ) and the individual optimal effort choice is $c_i^N = \frac{fR}{2N}$ and thus smaller than the socially optimal $c_i^{so} = \frac{fR}{2}$.[35] Intuitively, the quadratic cost function causes the marginal return to effort to decline as monitoring induces more effort, rendering monitoring individually unprofitable at the margin despite the fact that an outcome with more monitoring and higher effort would be collectively preferable – a classic social dilemma. Hence, our game consists of the sequence of two social dilemmas: first the dilemma in monitoring and secondly the dilemma in contributing. Overcoming the monitoring-dilemma might change the contribution stage into an incentive compatible investment problem. However, in an equilibrium of profit-maximizing agents the players refrain from monitoring as well as from contributing.

We conducted two experimental sessions of the new treatment we dub QUAD for its quadratic cost function, collecting eight new independent observations (with 48 new subjects), testing the model with the parameters $\kappa = 3.5$, $f = 6.377$ and $S = 20\%$. The other parameters remain as before. Because $\Delta\pi_{\text{invest}} \leq 0$, peer monitoring by profit-maximizing individuals should lead to $M^* = 0$. With the observer receiving 20% of the group production during those phases in which she is exogenously assigned or chosen by vote as the monitor, she is predicted to maximize earnings by selecting $M^* = 5$. These monitoring levels imply that team members maximize their individual earnings by each selecting effort levels $c_i^* = 2$ under peer and $c_i^* = 8$ under observer monitoring, with earnings of 15.37 and 19.16 respectively. The observer, in turn, earns a maximum of 12.5 when choosing $M = 0$ and 30 when choosing $M^* = 5$, assuming that team members respond in privately optimal fashion. Since we did not find a significant effect of the order, all independent observations were conducted using first the peer and second the observer monitoring phase in the first half, as before preceded by a 5 period phase with no monitoring.

[34] As prior to introducing the discrete version of the model of section 3, $\gamma$ and $\beta$ are again $\gamma = \frac{R}{N^2} \cdot (N - M)$ and $\beta = \frac{R}{N^2} \cdot (N - M + N \cdot M)$.

[35] See Appendix B for a detailed discussion of the quadratic model.

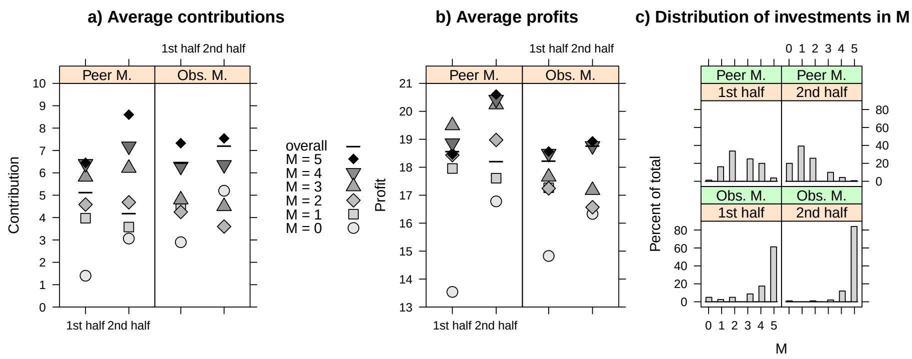


Figure 6: **a)** average contribution and **b)** profit by monitoring investment level and overall; **c)** distribution of the monitoring investment levels.

### Results

Even though the new parameters and cost function make monitoring more costly, reduce the gains from team production, and generate a pure free rider problem, the peers still manage to achieve high monitoring levels during the peer monitoring phase of the first half (periods 6 – 10), as can be seen in figure 6 c), thereby ensuring high contribution levels. Mean contribution is 5.19 under first half peer monitoring, versus 6.51 under first half observer monitoring and 3.72 in the no monitoring periods of phase 1. The differences in contributions between the phases with peer (Phase II) or observer (Phase III) monitoring and the phase without monitoring (Phase I) are statistically significant as are those between the two first-half monitoring phases (II and III):[36] Although observer monitoring in the first half achieves significantly higher contributions, peer monitoring is successful enough that given the 20% share that the observer claims, team members' profits are on average not significantly higher with Phase II peer than with Phase III observer monitoring as within group comparisons show ($p = 0.641$ exact Wilcoxon signed-rank test conducted over the independent observations). Only 3 of the 8 groups have a higher payoff under observer monitoring. Together with some dislike of sharing with the observer this might explain why only 1 out of 8 groups vote for the observer mechanism at the first vote round in QUAD.

However after the first vote the monitoring level of the peers declines considerably, as shown in figure 6 c).[37] This causes much lower contributions and profits[38] and leads to a growing tendency to choose the observer monitoring mechanism: 4 out of 8 groups vote for the observer in the 5th phase and 5 out of 8 groups do so in the last phase.

[36] $p = 0.008$ for public good vs. first half peer phase, $p = 0.008$ public good vs. first half observer phase and $p = 0.055$ for the comparison between first half peer and first half observer monitoring. (exact Wilcoxon signed rank test (two-sided))

[37] Exact Wilcoxon signed rank test: $p = 0.016$ (two-sided)

[38] Exact Wilcoxon signed rank tests: for the differences between contributions under peer in first half and those under peer in second half: $p = 0.0555$, between contributions under peer versus contributions under observer in second half $p = 0.016$, and the two parallel tests for profits: $p = 0.383$ and $p = 0.031$, respectively (all two-sided).

**Result 7.** *Although the introduction of a quadratic cost function which generates a pure free riding problem makes cooperation more difficult, peer monitoring is still substantial in Phase II and is favored by 7 of 8 groups in their initial votes. But investment in peer monitoring declines in Phases IV and V, leading to an increasing selection of the observer.*

The break-down of peer monitoring with repetition resembles the decline of contributions to a public good found in ordinary voluntary contribution experiments, which is not surprising since in the QUAD treatment peer monitoring is precisely such a public good. Thus, while the prediction of free riding from the outset is not supported either in the QUAD treatment or in standard finitely-repeated VCM experiments, a trend towards increased free riding over time can be observed, which in this case leads to the adoption of monitoring by a specialized residual-earning agent. The tendency that appears to emerge closely resembles that discussed by Alchian and Demsetz – i.e., insufficient incentives to engage in peer monitoring lead to the choice to organize the firm around a residual-claiming specialist monitor.[39]

# 6 Conclusion

We modeled team production as a process that varies in incentive features from a pure public goods game with free riding incentives to a privately profitable opportunity with payment in proportion to contribution. Thus, the incentive to contribute was a function of costly investment in a process denoted monitoring. We compared two institutions: In observer monitoring the monitoring is provided by a specialist who is compensated with a share of the team output. In peer monitoring the monitoring is provided by the production team members, who benefit from providing monitoring insofar as the better incentives it brings about lead to more contributions to production and hence to higher earnings. We investigated the claim that monitoring is usually provided by a residualclaiming specialist because team members have insufficient incentives and/or ability to coordinate on the provision of monitoring, and thus fail to provide adequate incentives to contribute effort to team production.

In our main model and experiment, incentives for peer monitoring are potentially adequate, but there exists a severe coordination problem. In our quadratic cost extension, there is a corresponding but more daunting problem of incentives for peer monitoring, a pure collective action dilemma. These conditions make success in peer monitoring at least improbable and, in the pure dilemma case, strictly inconsistent with self-interested choice. Our experimental subjects were surprisingly successful in peer monitoring, eschewing the opportunity to use a specialist monitor almost every time they chose between the two options in treatments where monitoring was equally costly to both peers and observer. Only when monitoring costs of team members were raised dramatically or when quadratic costs rendered peer monitoring a pure public good were there a substantial number of peer monitoring failures and

[39] It has been shown elsewhere that the decline in contributions to a public good can be prevented, delayed, or slowed by devices such as (a) permitting costly punishment of free riders (Fehr and Gächter (2000a), Page et al. (2005), Gürerk et al. (2006)) and (b) allowing pre-play communication (e.g.Brosig et al. (2003)). If such devices also slow or prevent the decline in peer monitoring, they would perhaps prevent observer monitoring from coming to be favored in the long run.

thus votes for a specialist monitor. Even in the treatment with higher monitoring costs for team members, some groups succeeded in peer monitoring and earned substantially more than those using a specialist, despite the higher cost. In the pure public good case, subjects showed hesitation to resort to specialist monitoring, but there were clear signs of evolution in that direction, rendering our laboratory a faithful incubator of firms with residual-claiming central monitors like those in Alchian and Demsetz's theory.

Our experiment is the first to nest the VCM or public goods game within a set of team incentive conditions, and to make the choice of organizational form or incentive regime an endogenous one. Our subjects behaved rationally in that they usually voted for the institution that gave them the highest earnings. However, their success at peer monitoring seems unlikely to be explained by individually rational behaviour of the kind modelled in standard theory. Given the severe difficulty of coordinating on efficient monitoring strategies, many subjects seemed to adopt an "over-provision" strategy which should in theory invite free riding but may not have done so in practice to the extent expected because of conditional willingness to cooperate. Conditional cooperation has been found among many subjects in recent VCM experiments, and it may have been enhanced in the present experiment by the desire to avoid ceding a significant share of output to a specialist monitor.

While our results cannot explain why mutual monitoring and profit- sharing is usually not relied upon as the main method of eliciting effort from workers in most actual firms, they are consistent with the fact that when profit-sharing is introduced, it is often successful at raising productivity (Weitzman and Kruse, 1990; Craig and Pencavel, 1995). A typical claim of writers on the topic is that despite the free-riding incentives that some associate with profit-sharing (Baker et al., 1988), workers in many firms respond to it by mutually monitoring one another's effort and working harder (Kruse, 1993) either because of a psychological identification with the firm's "bottom line", or to avoid the reproach of fellow workers (Kandel and Lazear, 1992). Thus, although one of our treatments succeeded in validating the logic of Alchian and Demsetz, the conditions under which mutual monitoring fails may be somewhat special, and the facts that most residual claims are not held by workers and that firms employ substantial amounts of top-down monitoring may be better explained by factors other than an inclination of workers to free ride in the provision of monitoring.

# References

Alchian, A. A. and Demsetz, H. (1972). Production, information costs, and economic organization. *The American Economic Review*, 62(4):777–795.

Baker, G. P., Jensen, M. C., and Murphy, K. J. (1988). Compensation and incentives: Practice vs. theory. *The Journal of Finance*, 43(3):593–616.

Banerjee, A. V. and Newman, A. F. (1993). Occupational choice and the process of development. *Journal of Political Economy*, 101(2):274–298.

Bowles, S. and Gintis, H. (1990). Contested exchange: New microfoundations of the political economy of capitalism. *Politics and Society*, 18(2):165–222.

Brosig, J., Weimann, J., and Ockenfels, A. (2003). The effect of communication media on cooperation. *German Economic Review*, 4(2):217–243.

Carpenter, J., Bowles, S., Gintis, H., and Hwang, S.-H. (2009). Strong reciprocity and team production: Theory and evidence. *Journal of Behavior & Organization*. forthcoming.

Craig, B. R. and Pencavel, J. (1995). Participation and productivity - a comparison of worker cooperatives and conventional firms in the plywood industry. *Brookings Papers on Economic Activity, Microeconomics Annual*, pages 121–160.

Croson, R. T. and Marks, M. B. (2000). Step returns in threshold public goods: A meta- and experimental analysis. *Experimental Economics*, 2:239–259.

Davis, D. D. and Holt, C. A. (1993). *Experimental Economics*. Princeton University Press.

Dow, G. K. (2003). *Governing the Firm: Workers Control in Theory and Practice*. Cambridge University Press, New York.

Dow, G. K. and Putterman, L. (2000). Why capital suppliers (usually) hire workers: what we know and what we need to know. *Journal of Economic Behavior & Organization*, 43(3):319–336.

Duffy, J., Ochs, J., and Vesterlund, L. (2007). Giving little by little: Dynamic voluntary contribution games. *Journal of Public Economics*, 91:1708–1730.

Estrin, S., Jones, D. C., and Svejnar, J. (1987). The productivity effects of worker participation - producer cooperatives in western economies. *Journal of Comparative Economics*, 11(1):40–61.

Eswaran, M. and Kotwal, A. (1984). The moral hazard of budget-breaking. *Rand Journal of Economics*, 15(4):578–581.

Eswaran, M. and Kotwal, A. (1989). Why are capitalists the bosses. *Economic Journal*, 99(394):162–176.

Fehr, E. and Gächter, S. (2000a). Cooperation and punishment in public goods experiments. *American Economic Review*, 90(4):980–994.

Fehr, E. and Gächter, S. (2000b). Fairness and retaliation: The economics of reciprocity. *Journal of Economic Perspectives*, 14(3):159–181.

Fischbacher, U. (2007). z-tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics*, 10(2):171–178.

Fischbacher, U., Gaechter, S., and Fehr, E. (2001). Are people conditionally cooperative? evidence from a public goods experiment. *Economic Letters*, 71(3):397–404.

Frohlich, N., Godard, J., Oppenheimer, J. A., and Starke, F. A. (1998). Employee versus conventionally-owned and controlled firms: an experimental analysis. *Managerial and Decision Economics*, 19(4):311–326.

Gradstein, M. and Nitzan, S. (1990). Binary participation and incremental provision of public goods. *Social Choice and Welfare*, 7:171–192.

Gürerk, O., Irlenbusch, B., and Rockenbach, B. (2006). The competitive advantage of sanctioning institutions. *Science*, 312:108–111.

Holmström, B. (1982). Moral hazard in teams. *Bell Journal of Economics*, 13(2):324–340.

Irlenbusch, B. and Ruchala, G. K. (2008). Relative rewards within team-based compensation. *Economic Inquiry*, 26:585–608.

Isaac, M. A. and Walker, J. M. (1988a). Group-size effects in public-goods provision - the voluntary contributions mechanism. *Quarterly Journal of Economics*, 103(1):179–199.

Isaac, M. R. and Walker, J. M. (1988b). Communication and free-riding behavior: The voluntary contributions mechanism. *Economic Inquiry*, 26:585–608.

Kandel, E. and Lazear, E. P. (1992). Peer pressure and partnerships. *The Journal of Political Economy*, 100(4):801–817.

Keser, C. (1996). Voluntary contributions to a public good when partial contribution is a dominant strategy. *Economics Letters*, 50(3):359–366.

Kihlstrom, R. E. and Laffont, J.-J. (1979). A general equilibrium entrepreneurial theory of firm formation based on risk aversion. *Journal of Political Economy*, 87(4):719–747.

Knight, F. H. (1921). *Risk, Uncertainty and Profit*. Hart, Schaffner & Marx; Houghton Mifflin Company, Boston.

Kremer, M. (1997). Why are worker cooperatives so rare? *NBER Working Paper*, 6118.

Kruse, D. L. (1993). *Profit Sharing: Does it Make a Difference?* Kalamazoo, MI: Upjohn Institute for Employment Research.

Ledyard, J. O. (1995). Public goods: A survey of experimental research. In Kagel, J. and Roth, A., editors, *Handbook of Experimental Economics*, pages 111–194. Princeton University Press.

MacLeod, W. B. (1988). *Equity, Efficiency and Incentives in Cooperative Teams*, volume 3. JAI Press, Greenwich.

Marglin, S. (1974). What do bosses do? the origins and functions of hierarchy in capitalist production. *Review of Radical Political Economics*, 6:60–112.

Marx, L. M. and Matthews, S. A. (2000). Dynamic voluntary contribution to a public project. *Review of Economic Studies*, 67:327–358.

Nalbantian, H. R. and Schotter, A. (1997). Productivity under group incentives: An experimental study. *American Economic Review*, 87(3):314–341.

Offerman, T., Schram, A., and Sonnemans, J. (1998). Quantal response models in step-level public good games. *European Journal of Political Economy*, 14(1):89 – 100.

Offerman, T., Sonnemans, J., and Schram, A. (1996). Value orientations, expectations and voluntary contributions in public goods. *The Economic Journal*, 106(437):817–845.

Page, T., Putterman, L., and Unel, B. (2005). Voluntary association in public goods experiments: Reciprocity, mimicry and efficiency. *The Economic Journal*, 115:1032–1053.

Potters, J., Sefton, M., and van der Heijden, E. (2009). Hierarchy and opportunism in teams. *Journal of Economic Behavior and Organization*, 69(1):39–50.

Sefton, M. and Steinberg, R. (1996). Reward structures in public good experiments. *Journal of Public Economics*, 61:263–287.

Shapiro, C. and Stiglitz, J. E. (1984). Equilibrium unemployment as a worker discipline device. *American Economic Review*, 74(3):433–444.

van de Kragt, A. J., Orbell, J. M., and Dawes, R. M. (1983). The minimal contributing set as a solution to public goods problems. *The American Political Science Review*, 77(1):112–122.

Weitzman, M. and Kruse, D. (1990). *Profit Sharing and Productivity*. Brookings Institution, Washington, DC.

# Appendix

## A Symmetric mixed strategy equilibrium in the discrete version of the model

Let $M^*$ be the lowest threshold of monitoring with $\beta > 1$ (i.e. individual rationality of full contributions) and $p$ be the probability of investing in monitoring. Thus for any player the probability that exactly $k$ other players invest is $\binom{N-1}{k} p^k (1-p)^{N-1-k}$.

Case 1: If $M < M^* - 1$ even by the investment of one player the threshold is not met. Then the payoff from investing in monitoring $\pi_{invest} = e - \kappa$ and the payoff from not investing in monitoring $\pi_{not\ invest} = e$ just differ by the costs of monitoring, because in both cases all players contribute $c^* = 0$ in the equilibrium of the contribution subgame. Thus, $\pi_{invest} - \pi_{not\ invest} = -\kappa$. The probability of $M < M^* - 1$ is given by $Pr(M < M^* - 1) = \sum_{k=0}^{M^*-2} \binom{N-1}{k} p^k (1-p)^{N-1-k}$.

Case 2: If $M > M^* - 1$ the threshold is already reached. An extra investment of another team member would decrease the team member's profit by the cost of investing in monitoring, because even without the extra investment all players already contribute their entire endowment in the contribution subgame. Thus $\pi_{invest} = e - \kappa + (R-1)e = R \cdot e - \kappa$, $\pi_{not\ invest} = e + (R-1)e = R \cdot e$ and $\pi_{invest} - \pi_{not\ invest} = -\kappa$. The probability of $M > M^* - 1$ is $Pr(M > M^* - 1) = \sum_{k=M^*}^{N-1} \binom{N-1}{k} p^k (1-p)^{N-1-k}$.

Case 3: If $M = M^* - 1$ then an investing player is pivotal, i.e. by his/her investment the player enables the team to exactly meet the threshold. Without the pivotal player's investment, all team members contribute 0 in the equilibrium of the contribution subgame, while with the pivotal player's investment all team members contribute the complete endowment in the equilibrium of the contribution subgame. Therefore, $\pi_{invest} = R \cdot e - \kappa$, $\pi_{not\ invest} = e$ and $\pi_{invest} - \pi_{not\ invest} = (R-1)e - \kappa$. The probability of $M = M^*$ is $Pr(M = M^* - 1) = \binom{N-1}{M^*-1} p^{M^*-1} (1-p)^{N-M^*}$.

For the symmetric mixed strategy equilibrium the expected payoff from investing has to equal the expected payoff from not investing, i.e.:

$$\begin{aligned} &\sum_{k=0}^{M^*-2} \binom{N-1}{k} p^k (1-p)^{N-1-k} \cdot (-\kappa) + \dots \\ + &\sum_{k=M^*}^{N-1} \binom{N-1}{k} p^k (1-p)^{N-1-k} \cdot (-\kappa) + \dots \\ + &\binom{N-1}{M^*-1} p^{M^*-1} (1-p)^{N-M^*} \cdot ((R-1)e - \kappa) = 0 \end{aligned} \tag{10}$$

This equivalently transforms into

$$\sum_{k=0}^{N-1} \binom{N-1}{k} p^k (1-p)^{N-1-k} \cdot \kappa = \binom{N-1}{M^*-1} p^{M^*-1} (1-p)^{N-M^*} \cdot (R-1)e$$

which reduces further to

$$\frac{1 \cdot \kappa}{(R-1)e} = \binom{N-1}{M^*-1} p^{M^*-1}(1-p)^{N-M^*}. \tag{11}$$

# B Quadratic model

When team work is modelled as a linear public goods problem the investment in monitoring resembles a coordination problem with equilibria incorporating positive monitoring expenses. Observing peer monitoring might thus be the result of equilibrium play or the attempt to do so. In order to raise the bar for peer monitoring we developed a model of team production in which the investment in monitoring itself is another public goods problem with free-riding incentives and thus lacks any equilibria with positive monitoring expenses. This cannot be done with linear costs of contributions. The intuition is that in that case there always exist strategy combinations in which the player's contribution causes an increase of the MPCR above 1. This transfers the public into a private good and makes the investment so profitable that positive investments in monitoring become individually rational. Therefore we reformulated the team production problem into one with a quadratic contribution cost model, generating the following individual profit for player $i$:

$$\pi_i = e - \kappa \cdot m_i - \frac{c_i^2}{f} + \beta \cdot c_i + \gamma \cdot C_{-i}. \tag{12}$$

The joint payoff level of all team members is:

$$\Pi = \sum_{i=1}^{N} \pi_i = N \cdot e - \sum_{i=1}^{N} \frac{c_i^2}{f} - \kappa \cdot M + R \cdot C. \tag{13}$$

leading to player $i$'s socially optimal contribution of

$$c_i^{so} = \frac{fR}{2} \tag{14}$$

What about the individual incentives for monitoring and contributing? For given investments in monitoring $m_j$ we derive the individually optimal contribution $c_i$ as:

$$c_i^*(M) = \frac{f}{2} \cdot \frac{N + M(N-1)}{N^2} R = \frac{f}{2}\beta \tag{15}$$

Hence, the individually optimal contribution only depends on the sum of all monitoring expenses $M$. Obviously, for $N = M$ the socially and the individually rational contribution levels coincide ((14) equals (15)). Hence, full monitoring ensures that a payoff-maximizing subject contributes the socially optimal contribution.

But is it in the self interest of individuals to invest in peer monitoring? An individual invests in peer monitoring if – ceteris paribus – the payoff difference between the optimal contribution level with and without monitoring investment is positive, i.e.:

$$\begin{aligned}
\Delta\pi_{invest} &= \pi_i(c_i^*(M_0+1)) - \pi_i(c_i^*(M_0)) \\
&= -\kappa - \frac{f}{4}R^2\left[\left(\frac{N+(N-1)(M_0+1)}{N^2}-1\right)^2-1\right]+\ldots \\
&\quad +\frac{f}{4}R^2\left[\left(\frac{N+(N-1)M_0}{N^2}-1\right)^2-1\right] \\
&= -\kappa - \frac{f}{4}R^2\left[\left(\frac{N+(N-1)(M_0+1)}{N^2}-1\right)^2-\ldots\right. \\
&\quad \left.-\left(\frac{N+(N-1)M_0}{N^2}-1\right)^2\right] \\
&= -\kappa - fR^2\frac{(N-1)^2(2M_0-2N+1)}{4N^4} \\
&= -\kappa + \frac{fR^2(N-1)^2(2N-1)}{4N^4} - \frac{fR^2(N-1)^2}{2N^4}M_0 \qquad (16)
\end{aligned}$$

If $\Delta\pi_{invest} \leq 0$ (which will be the case with our parameterization) no team member invests in monitoring and there will be no monitoring in equilibrium. If the level of monitoring is zero, then the equilibrium contribution is $c_i = \frac{fR}{2N}$, lower than socially optimal.

What are the incentives of the observer in that model? The payoff of the observer during the observer monitoring phase is $\pi_o = e_o - \kappa_o \cdot M_o + S \cdot R \cdot C$. The peers' payoff under observer monitoring is $\pi_i^o = e - \frac{c_i^2}{f} + (1-S)(\beta \cdot c_i + \gamma \cdot C_{-i})$. For a given monitoring level $M_o$ the team members' optimal contribution level is $c_i^{o*}(M_o) = \frac{f}{2}\frac{N+M_o(N-1)}{N^2}(1-S)R = \frac{f}{2}\beta^S$. This contribution level gives the observer the payoff of

$$\pi_o(c_i^{o*}(M_o)) = e_o - \kappa_o \cdot M_o + S \cdot R \cdot N \cdot c_i^{o*}(M_o).$$

Is it in the self interest of the observer to invest in peer monitoring? The observer will invest in monitoring if – ceteris paribus – the payoff difference between the optimal contribution level with and without monitoring investment is positive. The first difference in the observer's payoff of the monitoring level $M_o$ is

$$\begin{aligned}
\Delta_{\pi_o(M_o)} &= \pi_o(c_i^*(M_o+1)) - \pi_o(c_i^*(M_o)) \\
&= -\kappa_o + \frac{1}{2}fR^2(S-S^2)\left(1-\frac{1}{N}\right). \qquad (17)
\end{aligned}$$

As we see, if $\kappa_o < f\frac{R^2}{2}(S-S^2)\left(1-\frac{1}{N}\right)$ the observer will choose full monitoring (i.e. $M = N$), while with $\kappa_o > f\frac{R^2}{2}(S-S^2)\left(1-\frac{1}{N}\right)$ the observer will not monitor at all (i.e. $M = 0$).

If the observer fully invests in monitoring, the individually rational contribution levels of the team members are higher than in the equilibrium of peer monitoring with $\Delta\pi_{invest} \leq 0$: $c_i^{O*}(M_o = N) = (1-S)\frac{fR}{2} > c_i^N = \frac{fR}{2N}$ as long as $(1-S) > \frac{1}{N}$ (equivalentely $S < (1-\frac{1}{N})$). For $\Delta\pi_{invest} \leq 0$ invest the efficiency under peer monitoring in the Nash equilibrium is lower than the efficiency under observer monitoring as long as the same condition $S < (1-\frac{1}{N})$ holds. The efficiency under peer monitoring is $\frac{4e+fR^2(-1/N^2+2/N)}{4e+fR^2}$, while the efficiency under observer monitoring (including the observer) is $\frac{4e+fR^2(1-S^2)}{4e+fR^2}$. The team member Nash equilibrium profit in peer monitoring would be $\pi_i^N = e - \frac{fR^2}{4} \cdot (-\frac{1}{N^2} + \frac{1}{N})$ and for the observer monitoring $\pi_i^o = e - \frac{fR^2}{4} \cdot (1-S)^2$. Thus the team members' profit is higher with observer monitoring than with peer monitoring as long as $S < 1 - \frac{\sqrt{2N-1}}{N}$.

To sum up, in the parameter framework of our experimental study of the quadratic model the team members have no incentive to monitor and thus team production remains a voluntary contribution problem. In the subgame with observer monitoring, however, there will be full monitoring in equilibrium. This results in team members' payoffs which are – despite the observers' share – higher than under peer monitoring. Hence team members have an incentive to enter the subgame, i.e. to hire the observer.

# C Instructions for the linear production function, treatment PO25MC1

## Instructions to the Experiment

### General Information

At the beginning of the experiment you will be randomly assigned to one of **4 groups**. During the whole experiment you will interact only within your group. Each group contains **5 members** and **1 observer**. You will be informed whether you are a member or an observer. You keep your role during the whole experiment. The instructions explain the actions and payoffs of both the members and the observer.

### Course of action

The experiment consists of **30 rounds** which are divided into 6 phases of 5 rounds each.

### Payoff

The total payoff from the experiment consists of the sum of round payoffs of 30 rounds. At the end of the experiment your total payoff will be converted at an exchange rate of EUR 3 per 100 tokens.

### Please note

Communication is not allowed during the whole experiment. If you have some question please raise your hand out of the cabin. All decisions are made anonymously, i.e. no other participant learns the identity of the other decision makers. The payment is anonymous and takes place immediately after the experimental session.

## Phase 1 Group Project

***Member***

In each round of phase 1, every group member receives an **endowment of 10** tokens. You have to decide how many of these 10 tokens you contribute to the group project. The remaining tokens are assigned to your private account. The tokens contributed to the group project are **tripled** and equally distributed among all group members, while the tokens in the private account solely benefit the member.

**Calculation of a *member's round* payoff in phase 1**

A member's round payoff consists of two parts:

- **earnings from the group project** = **3** x sum of the contributions of all group members/ number of group members
- **tokens in the private account** = endowment – member's contribution to the project

Round **payoff of a member in phase 1**:
10 – member's contribution to the project +
+ 3 x sum of the contributions of all group members / 5

Here is an **example**:

| Member's contributions | Sum of contributions | 3x sum of conributions/5 | Member's payoff = 10 – contribution + 3 x sum contributions of all groups members/5 (equal shares) |
|---|---|---|---|
| 0 | 25 | 15 | 25 |
| 3 | 25 | 15 | 22 |
| 5 | 25 | 15 | 20 |
| 7 | 25 | 15 | 18 |
| 10 | 25 | 15 | 15 |

***Observer***

In each round of phase 1 the observer is asked to guess the sum of the contributions of "his/her" group.

## Calculation of the *observer's round* payoff in phase 1

The observer's payoff depends on the correctness of his/her guess. The closer the observer's guess is to the actual sum of contributions the higher is the observer's payoff.

The following example illustrates this:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sum of contributions | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Observer's guess | 0 | 5 | 10 | 20 | 25 | 30 | 35 | 50 |
| Observer's guessing error | 25 | 20 | 15 | 5 | 0 | 5 | 10 | 25 |
| Observer's profit | 13.33 | 15.00 | 17.14 | 24.00 | 30.00 | 24.00 | 20.00 | 13.33 |

Notice that the maximum which the observer can earn is 30 token and that the amount that the observer looses for guessing errors is the same for guessing too high a number as for guessing too low a number.

#### Information at the end of the round

At the end of the round each member as well as the observer is informed about the sum of the group members' contributions. The members are additionally informed about their individual payoff. The observer is additionally informed about the error in his/her guess and the resulting payoff.

## Phase 2 Investment in verification by group members

#### Member

In each round of phase 2 every group member receives an endowment of 10 tokens. Prior to the contribution decision each member may invest zero or one token in **verification** which will be deducted at the end of the period. The total investment in verification of all group members influences the way in which the earnings from the group (the tripled sum of contributions) project will be divided. There are three possibilities:

**Sharing rule 1 "Equal shares":** As in phase 1 the earnings from the group project will be divided **equally among all members if** 0 or 1 member invested in verification (like phase 1)

**Sharing rule 2 "Half/half": Half** of the earnings of the group project will be divided **equally among the group members** and the other **half in proportion to the individual contributions** of the group members **if** 2, 3, or 4 members invested in verification

**Sharing rule 3 "Proportionate":** The **entire earnings** from the group project will be allocated **in proportion to the individual contributions if** all 5 members invested in verification

After each member has completed his / her investment in verification each member as well as the observer is informed on the sharing rule to be applied. Then group members decide how many of their endowment of 10 tokens to invest in the group project (as in phase 1).

**Calculation of a *member's* round payoff in phase 2**

A member's payoff in phase 2 depends is calculated according to:

$$\begin{array}{l} 10 \\ -\text{contribution} \\ -\text{verification investment}+ \end{array} \begin{cases} \text{Equal shares of the tripled sum of contribu-} \\ \text{tions } \textbf{if} \text{ total investment in verification: } \textbf{0} \text{ or } \textbf{1} \\ \hline \text{half in equal shares + half in proportionate} \\ \textbf{if} \text{ total investment in verification: } \textbf{2}, \textbf{3} \text{ or } \textbf{4} \\ \hline \text{member's contribution tripled (propotionate)} \\ \textbf{if} \text{ total investment in verification: } \textbf{5} \end{cases}$$

Here is an **example**:

| Member's contributions | 3x sum of contributions/5 (Equal share) | Payoff* according to Sharing rule 1 "Equal-shares" | Sharing rule 2 "Half/half" | Sharing rule 3 "Proportionate" |
|---|---|---|---|---|
| 0 | 15 | 25 | 17.5 | 10 |
| 3 | 15 | 22 | 19.0 | 16 |
| 5 | 15 | 20 | 20.0 | 20 |
| 7 | 15 | 18 | 21.0 | 24 |
| 10 | 15 | 15 | 22.5 | 30 |

* the payoff still has to be reduced by the members' investment in verification

***Observer***

In each round of phase 3 the observer has to decide how many tokens he/she wants to invest in verification of "his/her" group. The calculation of the observer's payoff is as in phase 1.

**Information at the end of the round**

At the end of the round each member as well as the observer is informed about the sum of the group members' contributions. The members are additionally informed about their individual payoff. The observer is informed about the error in his/her guess and the resulting payoff.

## Phase 3: Verification by the *observer*

In phase 3 the **observer decides upon the level of verification**. The observer receives an endowment of 5 tokens and may invest from 0 up to 5 tokens in verification and keep the rest. Unlike the previous phases, the observer is not asked to guess the sum of the members' contributions. Instead, the observer receives **25%** of the **tripled** amount of the sum of all members' contributions. The remaining **75%** of the **tripled** amount of the sum of all members' contributions are distributed among the group members.

As in phase 2 the investment in verification influences the way in which the earnings from the group project (that is, 75% of the tripled amount, or $2\frac{1}{4}$ times the sum of the contributions) will be divided among the members. Again the three sharing rules described above are possible:

| | | |
|---|---|---|
| **Sharing rule 1 "Equal shares"** | **if** | the observer invests 0 or 1 tokens in verification |
| **Sharing rule 2 "Half/half"** | **if** | the observer invests 2, 3, or 4 tokens in verification |
| **Sharing rule 3 "proportionate"** | **if** | the observer invests 5 tokens in verification |

**Member**

The members are informed on the sharing rule to be applied according to the observer's investment in verification. The members decide how many of their 10 tokens they invest into the group project.

**Calculation of a *member's* round payoff in phase 3**

$$10 - \text{contribution} + \begin{cases} \frac{3}{4}\text{of equal shares of the tripled sum of contributions } \textbf{if} \text{ the observer invested } \textbf{0} \text{ or } \textbf{1} \text{ in verification} \\ \frac{3}{4}\text{(half in equal shares + half in proportionate share) } \textbf{if} \text{ the observer invested } \textbf{2}, \textbf{3} \text{ or } \textbf{4} \text{ in verification} \\ \frac{3}{4}\text{of member's contribution tripled (propotionate share) } \textbf{if} \text{ the observer invested } \textbf{5} \text{ in verification} \end{cases}$$

Here is an **example**:

| Member's contributions | 3x sum of contributions/5 (Equal share) | Payoff according to Sharing rule 1 "Equal-shares" | Sharing rule 2 "Half/half" | Sharing rule 3 "Proportionate" |
|---|---|---|---|---|
| 0 | 15 | 21.25 | 15.63 | 10.00 |
| 3 | 15 | 18.25 | 16.00 | 13.75 |
| 5 | 15 | 16.25 | 16.25 | 16.25 |
| 7 | 15 | 14.25 | 16.50 | 18.75 |
| 10 | 15 | 11.25 | 16.88 | 22.50 |

***Observer***

In each round of phase 3 the observer has to decide how many tokens he/she wants to invest in verification of "his/her" group.

**Calculation of an *observer's* round payoff in phase 3**

The payoff of the observer in phase 3 consists of the endowment of 5 minus his/her investment in verification plus 25% of the tripled amount of the sum of all members' contributions:

| |
|---|
| Round **payoff of an observer in phase 3**: |
| = 5 – investment in verification + |
| $\frac{1}{4}$x 3 x sum of member's contributions |

**Information at the end of the round**

At the end of the round each member as well as the observer is informed about the sum of the group members' contributions. The members are additionally informed about their individual payoff. The observer is additionally informed about the sum of the profits and the resulting payoff.

**Phase 4-6: Voting for the verification system**

At the beginning of phases 4, 5, and 6 group members vote for one of two possibilities: verification by the group members (as in phase 2) or verification by the observer (as in phase 3). For the next 5 rounds the verification type which was preferred by the majority of the group members is implemented. In other words, group members have the choice whether they want to implement the mechanism of phase 2 (that is, provide their own verification, if any) or the mechanism of phase 3 (that is, "hire the observer", who provides verification, if any) again for each of these sets of 5 rounds. The observer cannot vote.

**We wish you success!**

**NOTE: The other materials (examples and overview scheme) are on the internet at** http://data.cereb.eu/monitoring.html

# D Instructions quadratic production function

## Instructions

### General Information

At the beginning of the experiment you will be randomly assigned to one of **4 groups**. During the whole experiment you will interact only within your group. Each group has **5 members** plus **1 observer**, 6 in total. You will be informed whether you are a member or an observer. You keep your role during the whole experiment.

### Course of Action

The experiment consists of 60 periods which are divided into 6 phases of 10 periods each.

### Payoff

The total payoff from the experiment consists of the sum all 60 period payoffs. At the end of the experiment your total payoff will be converted at an exchange rate of EUR 1 per 100 tokens.

**Please note:**

During the whole experiment communication is not allowed. Please switch off your cell phone. If you have any question, please raise your hand out of the cabin. All decisions are made anonymously, i.e. no other participant gets to know the identity of the other decision makers. Payments are made anonymously and take place immediately after the experimental session.

## Phase 1: Group project

### Team member

In each period of Phase 1 each group member receives an **endowment of 10 tokens**. A discretionary amount out of these tokens can be contributed to the group project. Every contribution to the group project causes a **cost** for the contributing team member which are calculated as follows:

| Contributions | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total costs of contributions: | 0.0 | 0.16 | 0.63 | 1.41 | 2.51 | 3.92 | 5.65 | 7.68 | 10.04 | 12.7 | 15.68 |

If you contribute for example 2 this will cost 0,63 token and you will keep $10 - 0,63 = 9,37$ token of the original endowment of 10. The costs can be lower or higher than the contribution. The tokens that are contributed to the group project will be **multiplied by 3** and divided equally among the group members, notwithstanding whether they contributed or not.

### Calculation of a *group member's* period payoff in Phase 1

| | | |
|---|---|---|
| | **Endowment** | 10 |
| *minus* | **Costs of contribution** | According to the table above |
| *plus* | **Earnings from the group project** | 3x sum of contributions of all group members/number of group members |
| = | Group member payoff | |

You can gather more detailed payoffs from the attached table 1 (phase 1).

### Observer

In each period of Phase 1 the observer will be asked to guess the sum of contributions of his group.

### Calculation of the *observers* period payoff of Phase 1

The observer's payoff **depends on the precision of his/her guess**. The closer the observer's guess is to the actual sum of contributions the higher is the observer's payoff. The following examples illustrate this:

Notice that the maximum the observer can earn is 15 and that the amount of the payoff is symmetric: it does not matter if the guessing was too high or too low, only the size of the error matters.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sum of contributions | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| Observer's guess | 0 | 5 | 10 | 20 | 25 | 30 | 35 | 50 |
| Error of the guess | 25 | 20 | 15 | 5 | 0 | 5 | 10 | 25 |
| Payoff | 6.7 | 7.5 | 8.6 | 12.0 | 15.0 | 12.0 | 10.0 | 6.7 |

**Information at the end of the period**

At the end of each period, the group members and the observer will be informed about the sum of contributions of all group members, as well as their respective payoffs.

**Quiz**

1. a) What is your payoff if you contribute 2 and the other team members contribute 2 tokens on average? b) What is your payoff if you contribute 7 instead?
2. If the other group members contribute 10 tokens on average, a) what is your payoff when con tributing 10, and b) what is your payoff when you contribute 2?

## Phase 2: Investment in verification by the group members

**Team members**

In each period of Phase 2 each group member receives an **endowment of 10 tokens**. There are 2 consecutive decisions each member has to make:

1. Whether the group member invests in **verification of the contributions of the other group members** or not. The investment costs 3.5 tokens which will be deducted at the end of the period.
2. How many of the 10 tokens the group member will contribute to the group project (analogous to phase 1)

The total investment of all group members influences how the payment from the group project will be distributed. There are two "pots": the "*equal-distribution-pot*" and the "*according-to-contribution-pot*". The contents of the *equal-distribution-pot* will be divided in equal shares among the group members. The contents of the *according-to-contribution-pot* will be distributed directly according to the individual contribution.

**Importance of the Verification Mechanism** The investment in the verification mechanism determines the division of the payoffs from the group between the two pots:

- If no one invests in the verification mechanism all earnings from the team project go to the *equal-distribution-pot*
- If all group members invest in the verification mechanism all earnings from the team project will go in the *according-to-contribution-pot*

- In all other cases the earnings from the group project will be divided between the pots according to the investments in the verification mechanism (number invested/total number=share of the *according-to-contribution-pot*). For example if 2 out of 5 group members invest in the verification mechanism 2/5= 40% of the payoff will go to the *according-to-contribution-pot* and the remaining 60% to the *equal-distribution-pot* (for all)

You can gather more detailed payoffs from the attached table 2 (phase 2).
**NOTE** that you have to deduct the 3.5 tokens costs of the investment in verification there if you have invested in the verification mechanism. In other words, the table shows the earnings before deducting the cost of your investment in verification; if you are one of those who make that investment, your earnings are 3.5 tokens less than the number in the table.

***Observer***

In each period of phase 2, the observer is asked – as in phase 1 – to guess the sum of the group contributions. His payoff is calculated accordingly.

**Information at the end of the period**

At the end of the period each member and the observer will be informed about the number of investments in the verification mechanism, the sum of contributions, the distribution to the pots and their period payoff. The observer will be additionally informed about his guess and the resulting payoff.

**Quiz**

1. Compare the table 2 with no investment in verification with table 1 – is there a difference?
2. If 3 group members invest in the verification mechanism, what percent is divided equally and what percent is divided according to individual contributions
3. Suppose all members invest in the verification mechanism. What is your payoff as a team member a) if you contributed 5 and the others contributed 5 on average? What is your payoff b) if you contributed 10 and the others contributed 5 on average?
4. Now, suppose the others contribute 7 on average, how do the payoffs in question 3 change?

## Phase 3: Investment in the verification mechanism by the observer

In phase 3 the observer will not be asked for his guess. Instead **the observer** determines by his investment the degree of verification of the contributions of the group members. For this purpose she will receive an endowment of 5 token. Her investment thus specifies the **division between the two pots**. The more the observer invests in the verification mechanism, the greater is the share of the *according-to-contribution-pot* of the earnings. The observer will receive 20% of the group projects' earnings. The remaining 80% will be distributed between the pots for the distribution among the group members according to the observer's investment in the verification:

- If she does not invest in the verification mechanism, all earnings from the team project go to the *equal-distribution-pot*
- If she invests her complete endowment in the verification mechanism, all earnings from the team project will go to the *according-to-contribution-pot*
- In all other cases, the earnings from the group project will be *divided between the pots* according to the investments in the verification mechanism. For example, if he invests 2 tokens in the verification mechanism $2/5 = 40\%$ of the payoff will go to the *according-to-contribution-pot* and the remaining 60% to the *equal-distribution-pot*

You can gather more detailed payoffs from the attached table 3 (phase 3).

***Team members***

Team members will be informed about the investment of the observer. The investment of the observer in verification determines the division of the payoffs from the project. Each team member decides how much of his or her 10 token endowment to invest in the group project. Contributions lead to the same costs as in phase 1.

**Observer**

The observer decides in each period of phase 3 how many of his tokens he or she will invest in the verification mechanism of his/her group. The observer receives an endowment of 5 tokens. She is allowed to spend any amount between 0 and 5. The observer will keep tokens she does not invest. The observer will receive a share of 20% of the group project payoff.

**Information at the end of the period**

At the end of each period each member and the observer will be informed about the sum of contributions. The members additionally will be informed about the composition of their payoff. The observer additionally will be informed about the resulting payoff.

**Quiz**

1. If the observer invests 3 tokens in the verification mechanism, a) how many percent will a group member receive from the *according-to-contribution-pot* and b) how many from the *equal-distribution-pot*?
2. Suppose the observer invests 5 tokens in the verification mechanism. What is the payoff of a group member if the others invest on average 5 tokens and he or she invests 10 tokens? What if a group member invests 5 tokens?

## Phase 4-6: Vote on the verification system

At the beginning of phases 4, 5, and 6, group members vote for one of two possibilities:

- Verification of the contributions by the group members (like phase 2)
- Verification of the contributions by the observer (like Phase 3).

For the following 10 periods the verification system will be the one chosen by the majority of group members.

With other words: The group members might decide whether they want either the system of phase 2 (investment in verification by group members) or the system of phase 3 (investment in verification by observer) for 10 consecutive periods. This will be repeated twice. The observer cannot vote.

**NOTE: The other materials (e.g. the payoff tables) are on the internet at:**
http://data.cereb.eu/monitoring.html