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 observed 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.

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

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

(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, Jones, and Svejnar (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.

[2] See also the references to Alchian and Demsetz's hypothesis in many of the papers cited in the previous paragraph.

In a recent experimental study of work organization and incentives Potters, Sefton, and van der Heijden (2005) compare laboratory manager-less teams that play a standard 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, Godard, Oppenheimer, and Starke (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 $0 \le c_i \le e$ to contribute to a team production process, leaving $e - c_i$ for private production. The sum

[3] The numerous social dilemma experiments beginning with Fehr and Gächter (2000) or Carpenter, Bowles, and Gintis (2006), 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.

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 on 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 $m_i \in [0,...,1]$ 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:

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

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 $\pi_i = e - c_i + R \cdot C / N$. 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 production is a pure public good problem in which the team output is shared equally, however if a sufficient investment is made in monitoring individuals' contributions, then they can be paid according to their contributions as a result of which there will be an incentive to contribute and not to free ride.

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

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

where $C_{-i} = \sum_{\substack{j=1 \\ j \neq i}}^{N} c_j$ 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 marginal return from his/her own investment and the weight $\gamma = \frac{R}{N^2} \cdot (N - M)$ denotes the team member's marginal 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 his or her 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 the players decide on their contribution to the team project. We analyze the game by backward induction identifying the subgame perfect equilibria under the assumption that the 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 $0 \le c_i \le e$ may be part of a subgame perfect equilibrium. Now turn to the investment in monitoring. The subgame has multiple equilibria. There are two symmetric Nash equilibria in pure strategies: one in which each player does not invest in monitoring ($m_i = 0$) and the other one in which each player invests the N-th part of the amount necessary to make full contribution to the public good individually rational ($m_i = \frac{\widetilde{M}}{N}$). In addition, there is an infinite number of asymmetric pure strategy equilibria of the subgame which are all characterized by investments m_i satisfying $M = \widetilde{M}$.

Hence the public good dilemma of team production may be "resolved" in the monitoring phase prior to it. However, the investment in monitoring is a coordination problem with multiple equilibria, thus vulnerable to severe coordination failures.[4] If decision maker i believes that other group members will invest little in monitoring such that her investment m_i does not suffice to achieve $\widetilde{M}$, her best reply is not to invest. Similarly, if i believes that other group members will invest enough in monitoring to achieve $\widetilde{M}$, then her best reply is to abstain from monitoring—a situation resembling the incentive to free ride on monitoring that Alchian and Demsetz appear to have had in mind. Only if i believes that her investment is needed to exactly meet $\widetilde{M}$ is it rational for her to invest in monitoring.

Specialist monitoring

[4] Marx and Matthews (2000)

To overcome the coordination problem 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 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.[5]

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:

$$\pi_S = e_S - \kappa_S m_S + S \cdot C \cdot R \qquad \text{for the specialist} \qquad (3)$$

$$\pi_i^S = e - c_i + \beta^S \cdot c_i + \gamma^S \cdot C_{-i} \qquad \text{for the team member } i \qquad (4)$$

with the adjusted weight $\beta^S = (1-S) \cdot \beta$ denoting a team members' marginal return from his/her investment after deduction of the specialist's share and the adjusted weight $\gamma^S = (1-S) \cdot \gamma$ denoting a team member's marginal 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

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

[5] 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.

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 κ_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 $\pi_S = e_S - \kappa_s \cdot \widetilde{M}^S + S \cdot N \cdot e \cdot R > 0$.

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 problem through the actions of the team members and/or the decision of the specialist monitor. Because of the coordination problem, 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 $\pi_s > 0$ 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.

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 $M < T_1$ 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. Hence, the payoff function under peer monitoring is:

$$\pi_i = \begin{cases} e-\kappa\cdot m_i - c_i + \frac{1}{N}\cdot R\cdot C, & 0\le M < T_1 \\ e-\kappa\cdot m_i - c_i + \frac{1}{2}\cdot\frac{1}{N}\cdot R\cdot C + \frac{1}{2}\cdot R\cdot c_i, & T_1 \le M < T_2 \\ e-\kappa\cdot m_i - c_i + R\cdot c_i, & T_2 \le M \le N \end{cases} \tag{5}$$

In terms of β and γ this means:

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

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, a multiplier R = 3, the specialist's endowment e_S = 5 and the specialist's share S = 0.25. Then

$$\begin{cases} \beta = 0.6, \quad \gamma = 0.6 & 0\le M < T_1 \\ \beta = 1.8, \quad \gamma = 1.5 & T_1 \le M < T_2 \\ \beta = 3.0, \quad \gamma = 0 & T_2 \le M \le N \end{cases}$$

$$\begin{cases} \beta^S = 0.45, \quad \gamma^S = 0.45 & 0\le M < T_1 \\ \beta^S = 1.35, \quad \gamma^S = 1.125 & T_1 \le M < T_2 \\ \beta^S = 2.25, \quad \gamma^S = 0 & T_2 \le M \le N \end{cases}$$

Hence for $M \ge T_1$ full contribution to the team project is individually rational, because the individual return from investment β 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 these 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 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 equilibrium prescribes no investment in peer monitoring. All the equilibria with monitoring are asymmetric and hence very vulnerable to coordination failure. In case of $N = 5$ and $T_1 = 2$, 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. 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).[6] 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 = 0.75·30 and the observer earns her endowment (of 5) minus the monitoring investment plus 37.5 = 0.25·150.

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, there is a high risk of coordination failure. Failing to reach the sufficient level of monitoring leads to drastically lower individual payoffs of 9 and 10, dependent on whether the individual invested in monitoring or not.[7] Facing this risk, team members may decide to hire a specialist to make

[6] 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.

[7] 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.

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" 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 1).

Table 1 Step Structures

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 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 2). 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.

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 percent 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.[8] 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.

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

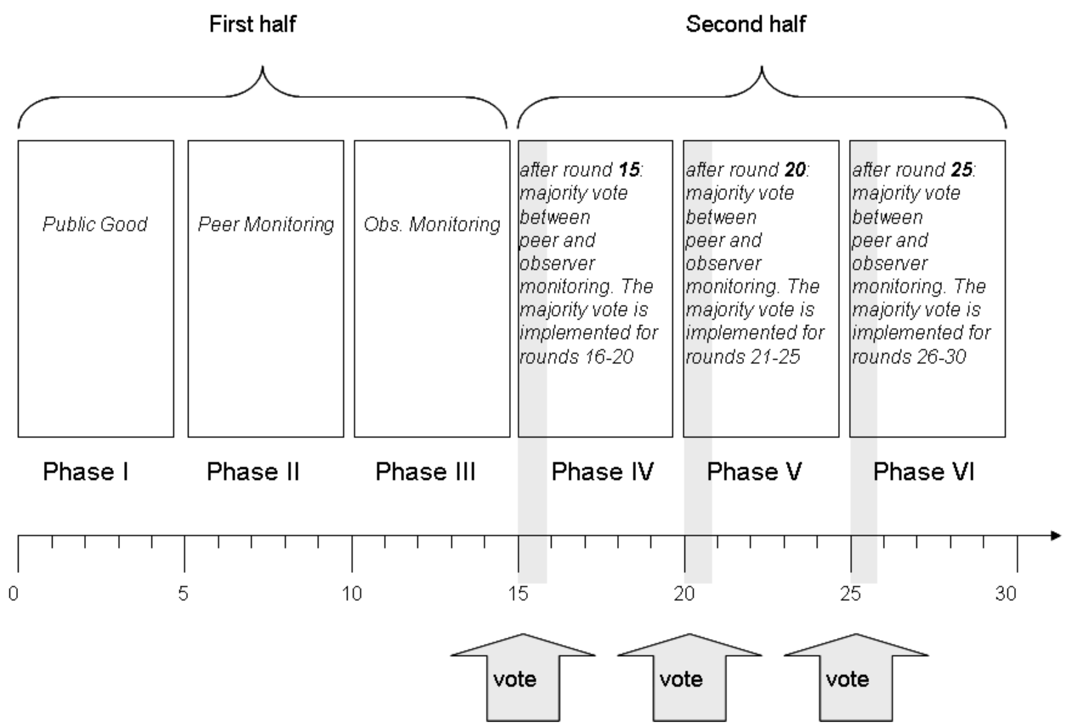

Figure 1 Schematic representation of the course of the interaction for PO

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 are discussed in the next section, we conducted sessions with an additional treatment that is otherwise like the OP45 treatment but in which the cost of a unit 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. We distinguish the two treatments by referring to them as OP45MC1 and OP45MC3, with the other three treatments also sharing the MC1 designation. Table 2 provides an overview of the five treatments.

Table 2 Treatment description

Treatment	Phase Sequence		Step structure	Cost per unit of monitoring	
	Phase II	**Phase III**		**Peer κ**	**Observer κ_S**
PO25MC1	Peer	Observer	Step Structure 2-5	1	1
OP25MC1	Observer	Peer		1	1
PO45MC1	Peer	Observer	Step Structure 4-5	1	1
OP45MC1	Observer	Peer		1	1
PO45MC3	Peer	Observer		3	1

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. Each subject sat in a separate compartment in the experiment lab at the University of Erfurt, did not know which other subjects were in his/her group, and had no communication with others apart from information about choices that was transmitted by computer. 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. All subjects were students who were recruited at the University of Erfurt using the Orsee System[9]. The experiment was conducted with the z-tree Software package (Fischbacher, 2007). Subjects 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.[10] Therefore, we

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

[10] The difference in average contributions and monitoring between OP and PO are not different at 10 % level (exact Mann-Whitney-U-Test) with one exception (OP25MC1 vs. PO25MC1 in the observer monitoring phase)

analyze the pooled treatments PO25MC1 and 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. 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. Therefore, we start off with the presentation of the result of the second half of play.

Did the voting process exhibit a preference for observer monitoring to avoid the co-ordination problem in peer monitoring? The answer is a surprisingly clear No! As Table 3 shows, 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.

Table 3 Choice of Observer or Peer Monitoring in the second half

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

Result 1: *In the four MC1 treatments, the observer is almost never chosen by the majority vote of the team members.*

How did the peer monitoring teams perform? In the majority of cases team members failed to reach an equilibrium level of monitoring. In 25MC1 an investment in monitoring of 2 was reached in 37.7 percent of the cases, while in 45MC1 the equilibrium level of 4 units of monitoring was only reached in 18.3 percent of all cases. This demonstrated the high vulnerability of monitoring to coordination failure. Nevertheless, 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 2a). They implemented HALF/HALF or ATIC in 93 percent of the cases. Figures 2b and 2c additionally show that contributions as well as payoffs under both sharing rules are extremely high.

Result 2: *In the MC1 treatments, peer monitoring performs extremely well: in 93 percent of the cases a rule capable of eliciting full contributions is reached; contributions are near 100 percent of endowments and payoffs are high.*

However, we observe an interesting difference between HALF/HALF and ATIC. A payoff-maximizing subject should contribute her full endowment under both division rules, because in both cases one unit of contribution is repaid by more than one, for all possible actions of the other team members. Nevertheless we observe that contributions under ATIC are on average 9.9, whereas contributions under HALF/HALF are on average 8.7. The difference is significant ($p < 0.001$, two tailed exact Wilcoxon test). The explanation for this phenomenon may be attributed to 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. However, role-of-thumb or boundedly rational reasoning could also explain some difference.

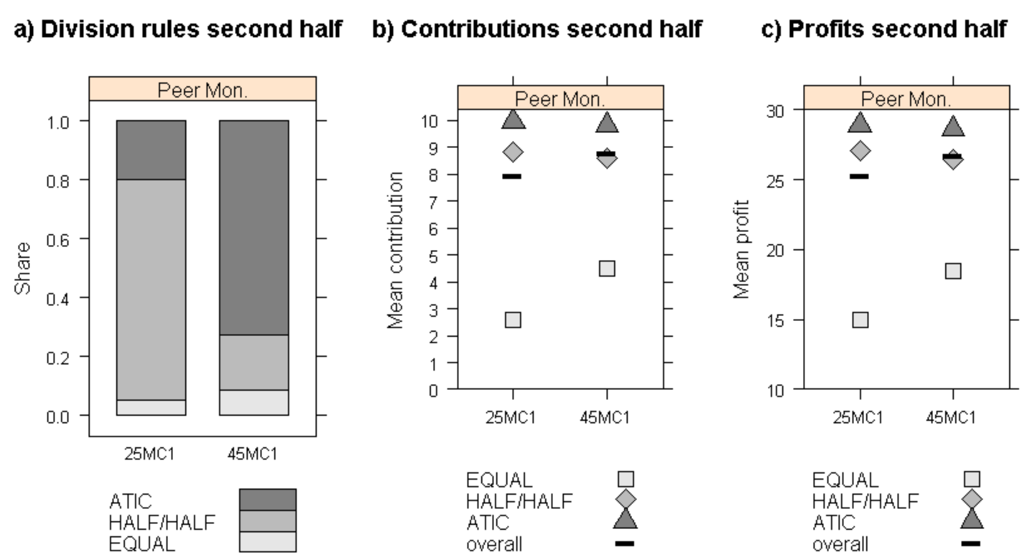

Figure 2: a) Frequency of implemented division rules; **b)** Contributions; **c)** Payoffs; displayed are averages over the observations in the second half

An interesting finding is that the average payoffs in 45MC1 are significantly higher than in 25MC1 (p=0.043 one sided Mann-Whitney U), 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 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 agree on an alternation rule in which one of the five team members will refrain from monitoring each period. Thus, most team members seem to have decided to monitor every period. Not only is the average cost of over-monitoring to each subject 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.

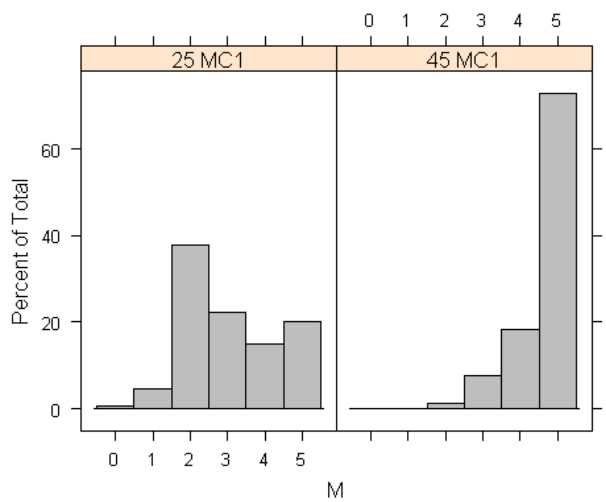

Figure 3: Histogram of the sum of investments in peer monitoring; displayed are averages over the observations Phases IV – IV.

5.2. Causes

What causes the clear results of the second half of the experiment? To answer this question it is useful to analyze behaviours in the first half of the experiment, with its exogenous phases of no monitoring, peer monitoring, and observer monitoring.

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 and decrease from there on. In all four treatments we observe a negative trend in contributions over time[11] which is in line with past experiments[12] 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.[13]

How did subjects respond to the various division rules? During the observer and peer monitoring periods of Phases II and III, subjects responded to HALF/HALF and ATIC division rules with considerable increases in contributions. There were, however, two mild surprises. First, as already noted for the endogenous rule phases, subjects contributed moderately but significantly more under ATIC than under HALF/HALF, even though a payoff-maximizing agent is predicted to contribute the full endowment under either division rule. Second, subjects tended to contribute somewhat less when the observer monitored than when the team members did.[14] Notice that the private marginal return from contributing effort is smaller under HALF/HALF compared to ATIC and smaller under observer monitoring than under monitoring. It seems that subjects responded to differences in marginal returns[15], even though full contribution is privately optimal (since β and $\beta_S > 1$) for both division rules and both assignments of the monitoring role.

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[11] A linear regression shows a negative time trend in contributions for Phase I (The standard public good phase). A regression is performed with the average (per group) contributions of Phase I as the dependent variable. The time coefficient is significantly negative at 1% for all treatments but the PO 45 MC1 treatment. (robust, Huber White standard errors).

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

[13] There is by now an immense literature attempting to explain this anomaly. Some of the explanations emphasize heterogeneity of agent preferences, a matter to which we return shortly.

[14] For 25MC1 and 45MC1, two sided exact Wilcoxon signed-rank test: HALF/HALF p=0.074, ATIC 0.025.

[15] Which is somewhat in line for example with Isaac and Walker (1988b) although the MPCR there was below 1 while in our case the subjects respond on different MPCR > 1 as well.

Result 3: *Responses to EQUAL division are consistent with those in the experimental literature on the voluntary contribution mechanism and with presence of a free-riding problem, though there is less free riding than theory predicts. Subjects also respond to changes in marginal private return associated with the difference between ATIC and HALF/HALF rules and with that between observer and peer monitoring, although theory predicts full contributions regardless of these differences.*

Peers managed to supply incentive-imparting monitoring at least as often as did specialist observers. The peers chose an incentive compatible mechanism in 95 percent of the cases, the observers in 82.5 percent (in the first half). This difference is significant (p=0.044, exact Wilcoxon signed rank test). Yet, as Figure 5a shows, observers failed to provide enough monitoring to reach HALF/HALF division more often than did peers in both 25MC1 and 45MC1.

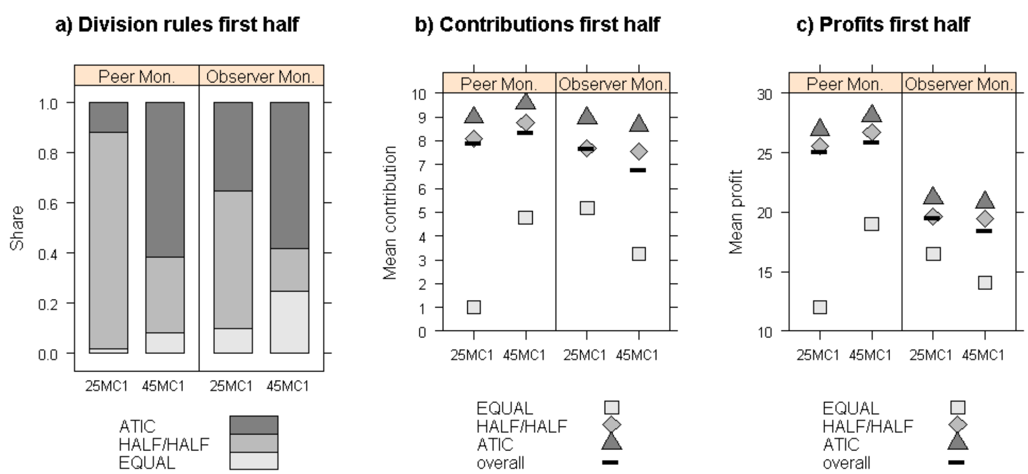

Figure 5: a) Frequency of implemented division rules; displayed are averages over the observations in the first half in the 25MC1 and 45MC1 treatments. **b)** Average contributions over the observations in the first half in the 25MC1 and 45MC1 treatments. **c)** Average profits over the observations in the first half in the 25MC1 and 45MC1 treatments.

Result 4: *Failure to achieve a division rule providing incentives to contribute the full endowment occurred less often in the exogenous peer than in the exogenous observer monitoring phases.*

It comes as a surprise that despite their coordination problem team members succeeded more often in achieving an incentive compatible allocation rule than observers. How did the teams manage the coordination problem? One explanation could be that subjects followed an "overprovision strategy"[16] ("invest in monitoring regardless of others' choices") because the benefits from full provision over-compensated the excess in provision. Another explanation is that subjects are guided by "non-standard" or social preferences. Suppose, for example, that some subjects are conditional cooperators[17] 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 were impossible or if no equilibrium strategies existed, for payoff-maximizers.[18]

Evidence that subjects with preference-based inclinations to cooperate account both for some contributions and some monitoring could take the form of 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, $p=0.016$).

Taking together the lower rate of achieving incentives to contribute fully and the higher costs under observer monitoring, it comes as no surprise that team members' earnings were significantly lower under exogenous observer monitoring than under exogenous peer monitoring ($p<0.01$ percent Mann-U-test). Indeed, in the first half in all

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[16] Note that in the setting of our experiment a group could succeed in monitoring even if only two members adhered to an overprovision strategy, in 25MC1, or if four adhered to it in 45MC1.

[17] In the sense of Fehr and Gächter (2000) and Fischbacher, Fehr, and Gächter (2001)

[18] Duffy, Ochs, and Vesterlund (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 absence of a payoff jump may explain some of the difference between behaviors in the treatments discussed thus far and those in our QUAD treatment (see Section 5.4, below).

our independent observations team members earned higher profits under peer monitoring than under observer monitoring.

Result 5: *Team members' earnings were lower under exogenous observer than under exogenous peer monitoring.*

This experience from the first half 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 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 continued preference for peer monitoring is rational.[19]

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. Obviously, "overinvestment" in monitoring is not in equilibrium, but it 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. 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.[20] Notice that the observer's cost remains at 1 per unit of monitoring. We col-

[19] 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.

[20] 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.

lected six independent observations in this treatment. Through this change monitoring by the observer should become more attractive because coordination and “overinvestment” in monitoring is more costly and hence can be expected to be more difficult to achieve.

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 percent of the 18 votes. Figure 6a 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 percent. 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 percent 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 6 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 6a 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 6b). The same tendency is observed when looking at profits (see Figure 6c).

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

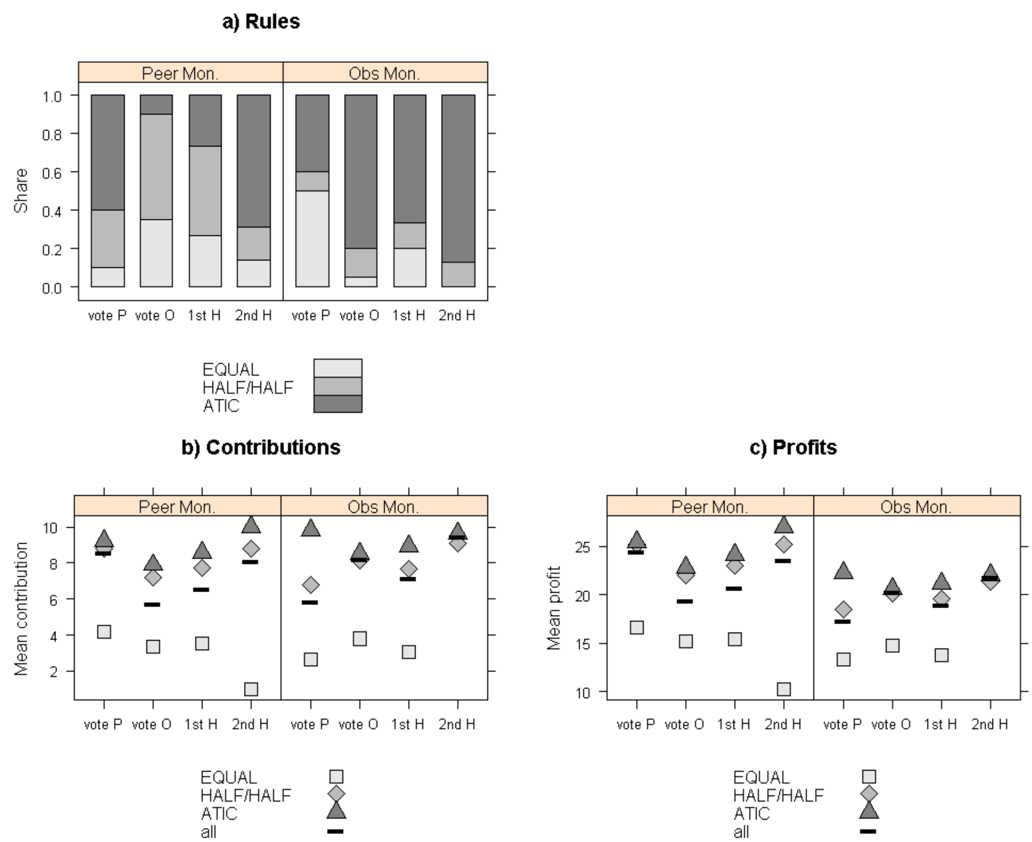

Figure 6: a) Frequency of implemented division rules; displayed are averages over the observations in the first half of PO45MC3 comparing those groups voting for the observer (vote O) with those who voted for peer monitoring (vote P), the overall share of the rules in the first half (1st H) and the second 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.

5.4 Extending the Model: The Zero Monitoring Equilibrium Case

Our model presented so far incorporates a coordination problem in monitoring. Thus, there exist equilibria with a positive level of monitoring, although coordinating on them may be nearly impossible. 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.[21] Specifically, we change the profit function for a team member in the peer monitoring phase to

$$\pi_i = e - \kappa \cdot m_i - \frac{c_i^{\ 2}}{f} + \beta \cdot c_i + \gamma \cdot C_{-i} \,. \tag{6}$$

where f is a cost function parameter. As a second change, we eliminate the step-like relationship between payoffs and monitoring, now allowing β and γ to increase and decrease, respectively with each unit by which M rises or declines.[22] During the observer monitoring regime the β and the γ in equation (6) are replaced by their by $(1-S)$ reduced counterparts β^S and γ^S.

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

$$c_i{}^* = \frac{f}{2} \cdot \frac{N + M(N-1)}{N^2} R = \frac{f}{2}\beta \tag{7}$$

Profit-maximizing peers will never invest in monitoring as long as:

$$\kappa \geq \frac{fR^2(N-1)^2}{2N^4}\left(\frac{N^2}{1-N} + M + \frac{1}{2}\right) \tag{8}$$

If (8) is fulfilled, the team members have no incentive to monitor and thus $M = 0$ leaving individual optimal effort choice $c_i^{\ N} = \frac{fR}{2N}$ smaller than the socially optimal $c_i^{\ so} = \frac{fR}{2}$.[23] Intuitively, the quadratic cost function causes the marginal return to effort

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

[22] The γ and the β are again $\gamma = \frac{R}{N^2} \cdot (N - M)$ and $\beta = \frac{R}{N^2} \cdot (N - M + N \cdot M)$

[23] See Appendix for the derivation.

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 40 new subjects), testing the model with the parameters $\kappa = 3.5$, $f = 6.377$ and $S = 20\%$.[24] (The other parameters remain as before.) Because (8) holds, 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 he is exogenously assigned or chosen by vote as the monitor, he 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, for 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.

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 (as op-

[24] The values assigned to κ and especially to f hint at the difficulty of finding parameters that yield the desired equilibrium properties. In fact, important features disappear with minor perturbations. The conditions of this section's equilibrium, and by extension of Alchian and Demsetz's intuition about the susceptibility of mutual monitoring systems to free riding, may therefore be somewhat special.

posed to the coordination problem of the main treatments), 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 7 c), thereby ensuring high contribution levels. c_i averages 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 (Phase II) peer or observer monitoring (Phase III) and the phase without monitoring (Phase I) are statistically significant as are those between the two first-half monitoring phases (II and III):[25] 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 II observer monitoring as within group comparisons show (p=0.641 exact Wilcoxon signed-rank test). 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.

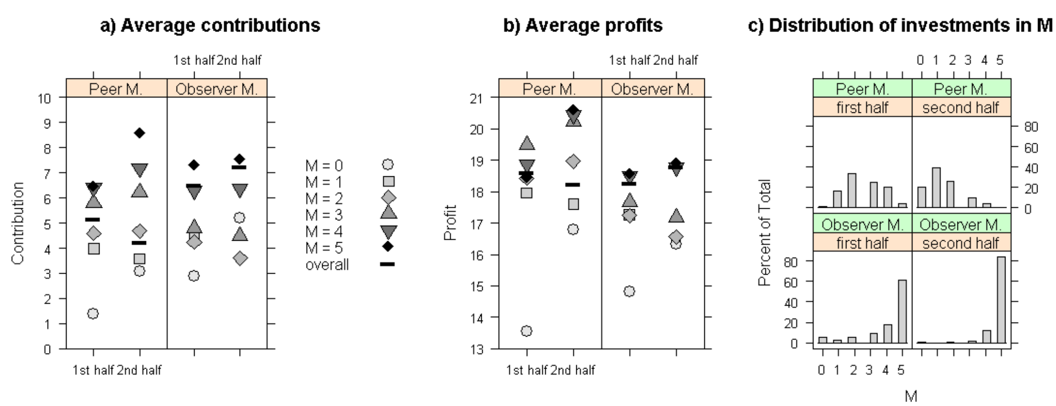

Figure 7 a) average contribution and b) profit by monitoring investment level and overall; c) distribution of the monitoring investment levels.

However after the first vote the monitoring level of the peers declines considerably, as shown in Figure 7 c).[26] This causes much lower contributions and profits[27] and leads

[25] 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. (both exact Wilcoxon signed rank test (two-sided))

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

to a growing tendency to choose the observer monitoring mechanism: 4 out of 8 groups vote ~~d~~ for the observer in the 5th phase and 5 out of 8 groups do so in the last phase.

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 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 is seen, 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. [28]

6. Conclusions

We modelled 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

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[27] 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 respective p=0.031 (all two-sided).

[28] 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 (2000), Page, Putterman, and Unel (2005), Gürerk, Irlenbusch, and Rockenbach (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.

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 residual-claiming 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 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 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[29], 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, Jensen and Murphy, 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 have to be explained by factors other than an inclination of workers to free ride in the provision of monitoring.

[29]Fehr and Gächter (2000), Page et al. (2005), Gürerk et al. (2006)

References

Alchian, Armen A., & Demsetz, Harold. (1972). Production, Information Costs, and Economic Organization. *The American Economic Review, 62*(4), 777-795.

Banerjee, A. V., & Newman, A. F. (1993). Occupational Choice and the Process of Development. *Journal of Political Economy, 101*(2), 274-298.

Brosig, Jeanette, Weimann, Joachim, & Ockenfels, Axel. (2003). The Effect of Communication Media on Cooperation. *German Economic Review, 4(2)*, 217-243.

Carpenter, Jeffrey P. , Bowles, Samuel, & Gintis, Herbert. (2006). Mutual Monitoring in Teams: Theory and Experimental Evidence on the Importance of Reciprocity. *IZA Working Paper, 2106*.

Craig, B., & Pencavel, J. (1995). Participation and Productivity - a Comparison of Worker Cooperatives and Conventional Firms in the Plywood Industry. *Brookings Papers on Economic Activity*, 121-&.

Davis, Douglas D., & Holt, Charles A. (1993). *Experimental Economics*: Princeton University Press.

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

Dow, Gregory K., & Putterman, Louis. (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., & Vesterlund, L. (2007). Giving little by little: Dynamic voluntary contribution games. *Journal of Public Economics, 91*(9), 1708-1730.

Estrin, S., Jones, D. C., & Svejnar, J. (1987). The Productivity Effects of Worker Participation - Producer Cooperatives in Western Economies. *Journal of Comparative Economics, 11*(1), 40-61.

Eswaran, M., & Kotwal, A. (1984). The Moral Hazard of Budget-Breaking. *Rand Journal of Economics, 15*(4), 578-581.

Eswaran, M., & Kotwal, A. (1989). Why Are Capitalists the Bosses. *Economic Journal, 99*(394), 162-176.

Fehr, Ernst, & Gächter, Simon. (2000). Cooperation and Punishment in Public Goods Experiments. *American Economic Review, 90(4)*, 980-994.

Fischbacher, Urs. (2007). Zurich Toolbox for Ready-made Economic Experiments. *forthcoming in Experimental Economics*.

Fischbacher, Urs, Fehr, Ernst, & Gächter, Simon. (2001). Are People Conditionally Cooperative? Evidence from a Public Goods Experiment. *Economic Letters, 71(3)*, 397-404.

Frohlich, Norman, Godard, John, Oppenheimer, Joe A., & Starke, Frederick A. . (1998). Employee versus conventionally-owned and controlled firms: an experimental analysis. *Managerial and Decision Economics, 19*, 311-326.

Gürerk, Ozguer, Irlenbusch, Bernd, & Rockenbach, Bettina. (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, Bernd, & Ruchala, Gabriele. (2008). Relative Rewards within Team-Based Compensation. *Labour Economics, 15*(2), 141-167.

Isaac, Mark R., & Walker, James M. (1988a). Communication and Free-Riding Behavior: The Voluntary Contributions Mechanism. *Economic Inquiry, 26*, 585-608.

Isaac, Mark R., & Walker, James M. (1988b). Group-Size Effects in Public-Goods Provision - the Voluntary Contributions Mechanism. *Quarterly Journal of Economics, 103*(1), 179-199.

Kandel, E., & Lazear, E. P. (1992). Peer Pressure and Partnerships. *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, Richard E., & Laffont, Jean-Jaques. (1979). A General Equilibrium Entrepreneurial Theory of Firm Formation Based on Risk Aversion. *Journal of Political Economy, 87*, 719-747.

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

Kremer, Michael. (1997). Why are Worker Cooperatives so Rare? *NBER Working Paper, 6118*.

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

Ledyard, John O. (1995). Public Goods: A Survey of Experimental Research. In J. Kagel & A. Roth (Eds.), *Handbook of Experimental Economics* (pp. 111-194): Princeton University Press.

MacLeod, W. Bentley. (1988). *Equity, Efficiency and Incentives in Cooperative Teams* (Vol. 3). Greenwich: JAI Press.

Marglin, Stephen. (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., & Matthews, S. A. (2000). Dynamic voluntary contribution to a public project. *Review of Economic Studies, 67*(2), 327-358.

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

Page, T., Putterman, L., & Unel, B. (2005). Voluntary association in public goods experiments: Reciprocity, mimicry and efficiency. *Economic Journal, 115*(506), 1032-1053.

Potters, Jan, Sefton, Martin, & van der Heijden, Eline. (2005). Hierarchy and Opportunism in Teams. *CentER DP, 109*.

Sefton, M., & Steinberg, R. (1996). Reward structures in public good experiments. *Journal of Public Economics, 61*(2), 263-287.

Weitzman, Martin, & Kruse, Douglas. (1990). *Profit Sharing and Productivity*. Washington, DC: Brookings Institution.

Appendix The 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*:

$$\pi_i = e - \kappa \cdot m_i - \frac{c_i^{\,2}}{f} + \beta \cdot c_i + \gamma \cdot C_{-i}\,. \tag{9}$$

The joint payoff level of all team members is:

$$\Pi = \sum_{i=1}^{N} \pi_i - = N \cdot e - \sum_{i=1}^{N} \frac{c_i^{\,2}}{f} - \kappa \cdot M + R \cdot C\,. \tag{10}$$

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

$$c_i^{\,so} = \frac{fR}{2} \tag{11}$$

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:

$$c_i * (M) = \frac{f}{2} \cdot \frac{N + M(N-1)}{N^2} R = \frac{f}{2} \beta \tag{12}$$

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 ((11) equals (12)). 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.:

$$\begin{aligned}\Delta_{\pi_i} &= \pi_i\left(c^*(M+1)\right) - \pi_i\left(c^*(M)\right) \\ &= -\frac{1}{f}\left(\left(c^*(M+1)\right)^2 - \left(c^*(M)\right)^2\right) - \kappa + R\left(c^*(M+1) - c^*(M)\right) \\ &= -\frac{1}{f}\left(c^*(M+1) - c^*(M)\right)\left(c^*(M+1) - c^*(M)\right) - \kappa + R\left(c^*(M+1) - c^*(M)\right)\end{aligned}$$

Since $c^*(M+1) - c^*(M) = \frac{fR(N-1)}{2N^2}$ and $c^*(M+1) + c^*(M) =$ $2 \cdot c^*(M) + \frac{fR(N-1)}{2N^2}$ the equation reduces to

$$\Delta_{\pi_i} = -\frac{1}{f}\left(2 \cdot c^*(M) + \frac{fR(N-1)}{2N^2}\right)\left(\frac{fR(N-1)}{2N^2}\right) - \kappa + R\left(\frac{fR(N-1)}{2N^2}\right)$$

which can be simplified to

$$\Delta_{\pi_i} = -\frac{fR^2(N-1)^2}{2N^4}\left(\frac{N^2}{1-N} + M + \frac{1}{2}\right) - \kappa \tag{13}$$

Hence, individuals do not invest in monitoring if $\Delta_{\pi_i} \leq 0$. Thus if

$$\kappa \geq -\frac{fR^2(N-1)^2}{2N^4}\left(\frac{N^2}{1-N} + M + \frac{1}{2}\right) \tag{14}$$

there will be no monitoring by rational subjects. Since $-\frac{fR^2(N-1)^2}{2N^4} < 0$ it follows that the incentive to invest in monitoring is decreasing with *M*, which means that the more the others invest in monitoring the lower are my incentives to do so. Because all team members' best reply is to refrain from monitoring, there will be no monitoring in equilibrium. If the level of monitoring is zero, then the equilibrium contribution is

$$c_i^{\ N} = \frac{fR}{2N}.$$

Hence, in equilibrium no peer monitoring takes place and contributions are 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:

$$\pi_i^O = e - \frac{c_i^2}{f} + (1-S)\left(\beta \cdot c_i + \gamma \cdot C_{-i}\right)$$

For a given monitoring level M_o the team members' optimal contribution level is

$$c_i^O * (M_o) = \frac{f}{2} \cdot \frac{N + M_o(N-1)}{N^2}(1-S)R = \frac{f}{2}\beta^S$$

This contribution level gives the observer a payoff of:

$$\pi_o\left(c_i^O * (M_o)\right) = e_o - \kappa_o \cdot M_o + S \cdot R \cdot N \cdot c_i^O * (M_o)$$

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

$$\Delta_{\pi_O(M_o)} = \pi_o\left(c_i * (M_o + 1)\right) - \pi_o\left(c_i * (M_o)\right) = -\kappa_o + \frac{1}{2} fR^2 (S - S^2)\left(1 - \frac{1}{N}\right) \qquad (15)$$

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:

$c_i^O * (M_o = N) = (1-S)\frac{fR}{2} > c_i^N = \frac{fR}{2N}$ as long as $(1-S) > \frac{1}{N}$ (equivalently $S < \left(1 - \frac{1}{N}\right)$).

The efficiency under peer monitoring in the Nash equilibrium is lower than the efficiency under observer monitoring as long as the same condition $S < \left(1 - \frac{1}{N}\right)$ holds. The efficiency under peer monitoring is $\frac{4e + fR^2\left(-\frac{1}{N^2} + \frac{2}{N}\right)}{4e + fR^2}$, while the efficiency under observer monitoring (including the observer) is $\frac{4e + fR^2\left(1 - S^2\right)}{4e + fR^2}$. The team member Nash equilibrium profit in peer monitoring would be $\pi_i^N = e - \frac{fR^2}{4}\left(-\frac{1}{N^2} + \frac{1}{N}\right)$ and for the observer monitoring $\pi_i^O = e - \frac{fR^2}{4}(1-S)^2$. 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.