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Effort Complementarity and Team Size, An Experimental Analysis of Moral Hazard in Teams

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Abstract

We use laboratory experiments to analyze the effects of team size in a voluntary contribution mechanism model when contribution levels are either complementary or substitutes. A simple model shows that different team production functions provides different incentives for its members according to team size. When contributions are substitutes within teams, bigger groups increases free-riding by the decreasing marginal per capita return of effort. On the other hand, if contributions are complementary within teams, in theory, group production could increase with group size. Our results show that when efforts are substitutes the contribution level is significantly higher than when efforts are complementary and that, for both production functions, smaller groups induce higher contribution levels.

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1 Introduction

A significant share of productive activities is based on team work, which means group incentive schemes are key to enhance performance. For example, 78% of the large firms in the US organize their employees in self-managed teams (Lazear and Shaw, 2007), and around three quarters use some team-based incentive pay plans (Ledford et al. 1995). Team-based incentives work differently according to how the individual contributions affect the final outcome (Adams 2002). One can think about this issue as a problem of voluntary contribution to public goods, where the common outcome is a function of the individuals' contributions to the team (see Zelmer 2003 for a survey).

In voluntary contribution models, when individual contributions are substitutes within a team, moral hazard in teams emerges (Holmstrom 1982). Since individuals share with the team the returns of their effort - known as the 1/N problem as in Kandel and Lazear (1992) -, they have incentive to free ride on others contributions which leads to inefficient allocations. In this setting, bigger teams generate more incentives to free riding and leading to more inefficient allocation (Isaac and Walker 1988). However, when individuals' contributions are complementary within a team, the marginal return of the individual effort depends on the effort exerted by the other team members. Thus, individuals have no incentive to free ride, but coordination issues can lead to inefficient allocation. The effect of team size in this setting is still disputable, since it could make coordination more difficult (Anderson et al. 2001) or improve performance (Rotemberg 1994; Knez and Simester 2001).

In this paper, we examine which of these two dimensions leads to more efficient allocations in a voluntary contribution mechanism: team size or effort complementarity. We also ask if effort complementarity potentializes the adverse consequences of big groups. To shed light to these questions, we use laboratory experiments based on a public good model similar to Nalbatian and Schotter (1997). We use a between-subject design, analyzing the decision of 72 students divided into different experimental sessions.

We find smaller contributions in bigger groups for both cases, for complementary or substitutable efforts. We also find that, for a given team size, substitute efforts within teams produced a higher contribution level than teams with complementary efforts. We find weak evidence that effort complementarity potentializes the inefficiencies generated by big teams. We use data to calculate the Quantal Response Equilibrium (McKelvey and Palfrey 1998) of the game where efforts are complements, and compare them with the Nash equilibria from the model with substitute efforts. This exercise corroborates the results.

Our results are consistent with Isaac and Walker (1988) in finding that bigger teams provide more incentives for free-riding when the marginal per capita return (MPCR)[1] decreases with the group size. Andreoni (1988), Kandel and Lazear (1992) and Carpenter (1999) also find similar conclusions. Adams (2002) finds that the decreasing MPCR problem holds for substitute production functions, but it does not hold when efforts are complementary. Cason and Khan (1998), however, argue that inefficiency may be a coordination problem. Our results regarding complementary efforts support this idea.

[1] The MPCR is the marginal product observed by each player for contributing to the public good.

Our main contribution is to study simultaneously these two characteristics, comparing how different team sizes affect different production functions, and how different production functions affect different group sizes. We find that in the absence of other incentive mechanisms - such as monitoring, communication, punishment, etc - coordination issues related to effort complementarity can generate more inefficiency than standard free riding problems. Further, bigger groups make coordination more difficult, creating more inefficiency.

The paper is organized as follows. Section 2 presents the theoretical framework that guides our laboratory experiment, which we describe in Section 3 along with the hypothesis to be tested. We present the results in Section 4, and Section 5 concludes.

2 Theoretical Framework

We model a basic public good voluntary contribution mechanism, similarly to Nalbatian and Schotter (1997) in which individuals have private costs but common benefits. This is a standard strategic game where moral hazard emerges within teams as individuals have an incentive to free ride on the contributions of their teammates. Suppose a group of N individuals, each endowed with w. Individual, i, simultaneously chooses how much of his endowment to allocate to a Group Account (GA), c_i, and a Private Account (PA), $w - c_i$.

The GA gives equal return to all group members - which is a function of all contributions $Y(c_1, ..., c_N)$ - while the cost of contributing to the GA is a function of the individual contribution only, given by c_i^2/γ, where γ is a constant. Denote $c_{-i} \equiv \{c_1, ..., c_N\}/c_i$ the contribution of the other group members except i. Therefore, the individual utility is

$$u(c_i, c_{-i}) = \alpha Y(c_i, c_{-i}) - \frac{c_i^2}{\gamma} + w - c_i \tag{1}$$

where α is the marginal utility of the GA's return (or the price of the public good).

We analyze two return functions. First, as in a standard public good model, the contributions are substitutes: $Y_s(c_i, c_{-i}) = \frac{\sum_{j=1}^{N} c_j}{N}$. Second, contributions are complements: $Y_c(c_i, c_{-i}) = \min\{c_1, ..., c_N\}$. Note that in the second one, individuals have no incentive to free ride.

The efficient contribution level (c^P) is the contribution that maximizes all group members profits. Since agents are symmetric, the efficient contribution is given by the symmetric contribution level which makes the marginal return equal to the marginal cost of contributing to the GA: $c^P = \frac{\gamma}{2}(\alpha - 1)$.

When contributions are substitute, $Y_s(.)$, each individual internalizes that only the N-th part of his contribution is productive. In this setting, the unique pure strategy Nash equilibrium is $c_i^* = \frac{\gamma}{2}\left(\frac{\alpha}{N} - 1\right) < c^P$. We can see that the equilibrium contribution is decreasing with group size.

When contributions are complementary, $Y_c(.)$, the game has a continuum of pure strategy Nash equilibria. Any symmetric contribution smaller than or equal to c^P is a Nash equilibrium. Inefficient equilibria here do not emerge from free riding, but from coordination failure. As a consequence, the group size does not affect the set of equilibria.[2] Therefore, the set of pure strategy Nash equilibria is not very informative in this case. A different solution concept commonly used in this class of games is the quantal response equilibrium (QRE) of McKelvey and Palfrey (1998). The main difference between this solution concept and the Nash one is that it assumes individuals can make mistakes when choosing which pure strategy to play, as detailed below.

Let $f_i(c)$ be agent i's probability density function of contributing c, and $F_i(c) = \Pr[C \leq c]$. Agent i's expected payoff depends on the $n-1$ other contributions. Let $G_i(c)$ be the distribution function of the minimum contribution of the other $n-1$ agents, $G_i(c) = 1 - \prod_{j \neq i} (1 - F_j(c))$, and let $g_i(c) = \frac{dG_i(c)}{dc}$. Agent i's expected payoff is given by: $\pi_i^e(c_i) = \alpha \int_0^{c_i} (1 - G_i(y))\, dy - \frac{c_i^2}{\gamma} + w - c_i$.[3] The QRE is the fixed point of the agent's best response functions when they maximize their expected payoffs. We can state that there is a unique QRE of this game, with associated expected contribution c^{QRE}.[4] Note that the density functions $f_i(.)$ and $G_i(.)$ are affected by group size, larger groups leading to lower equilibrium contributions.

There is one last interesting question which cannot be addressed theoretically: for a given group size, which return function leads to higher equilibrium contributions, the substitute or the complementary functions? This is an empirical question, which we use experiments to assess.

3 Experiment Design

We are interested in analyzing the effects of group sizes in the voluntary contribution mechanism when contribution levels are either complementary or substitute. To assess this point, we ran a *between-subject* design experiment with a total of 4 sessions, one session for each of the following treatments: substitute contributions with groups of 3, substitute contributions with groups of 6, complementary contributions with groups of 3, complementary contributions with groups of 6. The experiments were computer based using the Ztree software (Fischbacher 1999). We had 18 subjects in each session, totaling 72 participants. Subjects were inexperienced undergraduate students at Getulio Vargas Foundation majoring in different courses.

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[2] This can be seen by individuals best response function:

$$BR_i(c_i, c_{-i}) = \begin{cases} \min\{c_{-i}\} & \text{, if } \min\{c_{-i}\} \leq c^P \\ c^P & \text{, otherwise.} \end{cases}$$

[3] This expression is derived when $\pi_i^e(c_i) = \alpha \int_0^{c_i} y g_i(y) dy + p c_i (1 - G_i(c_i)) - \frac{c_i^2}{\gamma} + w - c_i$ is integrated by parts.

[4] Players strategy space if bounded, which guarantees the existence of QRE (see Proposition 3, Corollary 1 of Anderson et al., 1997). Continuous density function guarantees that any QRE must be symmetric across players (see Propositions 2 and 3 in Anderson, Goeree and Holt, 2001). Since a density function is completely determined by a first-order differential equation and its value when $x = 0$, we have uniqueness.

Each session consisted of 25 decision rounds with no practice periods. We used the *strangers* protocol in which new groups are randomly rearranged in each period. This design is used to mimic a one-shot game in which subjects do not know the identity of the other group members, neither their past actions. Standard terminology was used during the sessions, where agents are asked to make investment decisions in two accounts: a Group Account (the public good) and a Private Account. Any reference to social contribution was avoided in order to not bias the agent's decisions.

All sessions were conducted in a similar way: we made a short introduction asking for silence during the session; participants were given some time to read the instructions; we read aloud the instructions; individual doubts were answered privately; and finally the game began. There were no trial periods. We opted to present a cost table in the instructions to make the contribution space discrete and simplify agents' decisions, following Saijo and Nakamura (1995). Each session lasted around 70 minutes, including payment time. Each participant received a US$ 4.10 show up fee and, summing the experiment's gains, the total payment averaged US$ 6.25.[5]

At the beginning of each decision round, groups were randomly formed. Each subject received an endowment of 100 *tokens*[6], and was asked to type on his computer the amount he would like to allocate to the Group Account. The endowment amount not allocated in the Group Account was allocated to his Private Account. After all participants had made their decision, a result screen presented: (i) the amount the subject allocated to the Group Account, c_i; (ii) the return of the Group Account, $Y(c_i, c_{-i})$; (iii) and his profits. The history of these information was always available on the computer screen.

The parameters values were chosen in a manner to guarantee interior solution, $(\alpha, \gamma, w) = (11, 15, 100)$. Under these parameters, the efficient contribution level is $c^P = 75$. In the treatment where contributions to the Group Account are substitutes, the Nash equilibrium contribution level is equal to 20 and 6.25, when groups have 3 and 6 members, respectively.[7]

3.1 Substitute Contributions Treatment

In this treatment, the Group Account return was given by the average contribution in the group, Y_s. We ran one session with groups of 3 and the other with groups of 6. We tested the two hypotheses derived from the theoretical framework.

Hypothesis 1. When contributions are substitute, subjects contribute less than the Pareto efficient level.

Hypothesis 2. When contributions are substitute, individuals in larger groups contribute less than individuals in smaller groups.

[5]US$1 = R$ 2.45. Exchange rate from November 2005.

[6] *Tokens* is the experimental monetary unity.

[7]We do not impose any assumptions on the QRE's parameters, so equilibrium will be calculated using the empirical contribution distribution.

3.2 Complementary Contributions Treatment

In this treatment, the Group Account return was given by the minimum contribution in the group, Y_c. We ran one session with groups of 3 and other with groups of 6. From the theoretical framework:

Hypothesis 3. When contributions are complementary, subjects contribute less than the Pareto efficient level.

Hypothesis 4. When contributions are complementary, individuals in larger groups contribute less than individuals in smaller groups.

These four hypotheses are derived from the theory. We also test two empirical hypotheses outside the model:

Hypothesis 5. For a given group size, subjects' contribution is higher when contributions are substitute than when contributions are complementary.

Hypothesis 6. The inefficiencies from larger groups are bigger when contributions are complementary than when contributions are substitute.

4 Results

Figure 1 presents the average public good (Group Account return) along the periods in each session. It is evident from the figure that contributions in all treatments were substantially below the efficient level, which is equal to 75. Also, we can see that both treatment variables, the group size and the production function, seem to influence individuals contributions, and the final public good level. In particular, we observed a lower contribution level in the treatments with complementary contributions, for bigger group sizes.

Other salient feature of Graph 1 is that we can observe that public good provision decreased in the early periods in all sessions. Since we did not have trial periods, these negative trends may be due some learning or coordination process, and are frequently observed in the literature. However, our theoretical framework is a static model, which does not account for any initial learning. To overcome this problem, we perform all analysis for 3 subsamples: all periods, dropping the first 5 periods, and dropping the first 10 periods.

Table 1 presents the summary statistics for the different sample periods. We clearly fail to reject Hypotheses 1 and 3, which state that individual contribute less than the efficient level in all treatments. We can also see that in both cases, substitute or complementary contributions, the smaller groups supported a higher contribution level than bigger groups. This would mean that we also fail to reject Hypotheses 2 and 4.

We formally test our Hypotheses by regressing individual contribution and public good level on period, treatment dummies (one for groups of six and one for complementary contributions), and the interaction of these two dummies, as in the equation below:

$$y_{it} = \beta + \beta_6 Group6_i + \beta_C Compl_i + \beta_{C6} Group6_i * Compl_i + \delta_t + \epsilon_{it}$$

where y_{it} can be contribution of subject i in period t, or the public good implemented in group i in period t. δ_t are period fixed effects.[8]

The estimation results are presented in Table 2. We can see that β_6 is negative and statistically significant. That is, bigger groups show more shirking, independent of the production function, and we fail to reject Hypotheses 2 and 4. This result is not new and is in line with the theory and the findings from previous literature.[9]

Also, β_C is negative and significant as well, suggesting that groups in which efforts are substitutes provide less incentive to free-ride than groups with complementary efforts, for any group size. Therefore, we fail to reject Hypothesis 5.

When we drop the very initial periods, the coefficient of the interaction of bigger groups with complementary contributions, β_{C6}, is also negative and significant. This means that the inefficiency generated by bigger groups through the reduction in contribution is potentialized when contributions are complementary. This suggests that coordination issues associated to the complementary production functions are more affected by the group size than free riding incentives related to a substitute production function. Therefore, we fail to reject Hypothesis 5.

An alternative way to assess Hypothesis 5, is to use the contribution's empirical distribution to calculate the QRE of the games with complementary contributions and compare with the Nash equilibria. We first estimate agents cumulative distribution function, $F(x)$, using the contributions empirical distribution.[10] Then, we calculate the distribution function of the minimum contribution of the other $n-1$ agents, and subjects' expected payoff function (2), plotted in Figure 2. The QRE is the contribution that maximizes player's *ex ante* utility. Therefore, the QRE for the treatment with groups of three is equal to 14 and for the treatment with groups of six is equal to 4, both smaller than the Nash equilibria from the game with substitute contributions.

Curiously, we observed that the average contribution level in the smaller groups were fairly close to the Nash equilibrium level, in the substitute case, and the estimated QRE, in the complementary case. However, when looking at the treatments with groups of six we observe that individuals contributed above the equilibrium level. This means that there was actually an over-contribution in the treatments with bigger groups. Bigger groups indeed create perverse incentives to public good contribution, however, for some reason outside the scope of this paper, they are less harmful than the theory predicts.[11]

[8] Results are not affected if we drop period fixed effects.

[9] Andreoni (1988), Kandel and Lazear (1992), Adams (2002), Alchian and Demsetz(1972), and Isaac and Walker (1988).

[10] We also estimated the QRE using a non-parametric estimation of agent's contribution density function. The results are quite similar, so we opted to use the empirical distributions because it requires less assumptions.

[11] Our intuition is that this over-contribution may be due to calculation errors when facing several partners. The idea is that agent would not be able to evaluate all best response functions when playing with many people, and would use some rule of thumb, or act as if playing with a representative agent.

5 Conclusion

There exists a discussion in the literature about the effects of group size in the voluntary contribution mechanism when contribution levels are either complementary or substitute. Andreoni (1988) and Adams (2002) argue that different production functions provide different incentives for the agent throughout scale changes. In Kandel and Lazear (1992), it is argued that when effort levels are substitutes, bigger groups provide more incentives for free-riders. On the other hand, in Adam (2002), Knez and Simester (2001) and Rotemberg (1994) it is shown that if efforts are complementary, the public good provision may increase together with the group size.

In this paper we use laboratory experiments to identify which is the predominant characteristic to induce high effort levels within teams: group size or effort complementarity. Our results show that for any production function, bigger groups induce lower contribution levels than smaller groups. It is interesting that in the treatments with smaller groups we observed empirically the contribution level predicted by the theory, while in the treatments with bigger groups we observed over-contribution. This suggests that bigger groups indeed provide more incentive to shirking than smaller groups, however in a lesser extent than the expected by the model. We also find that, for both team sizes, the substitute production function induces higher contribution levels than the complementary one.

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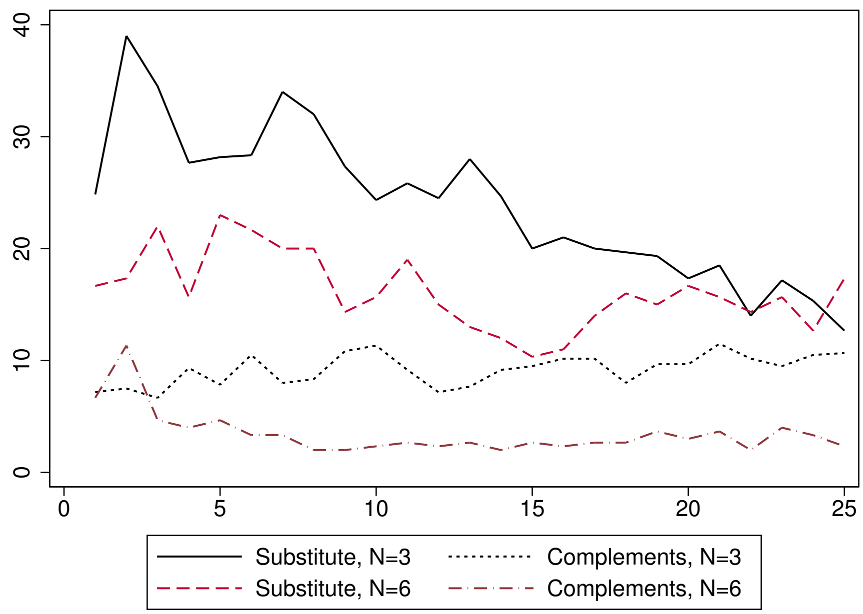

Figure 1: Average public good (Group Account) level along the periods

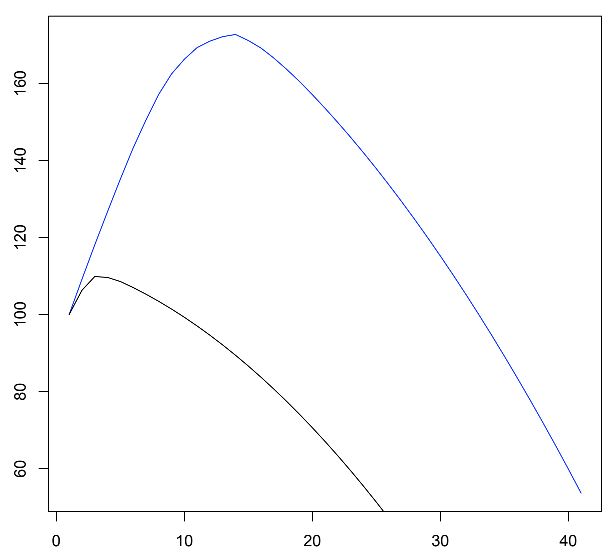

Figure 2: Subjects' expected payoff in a QRE

Table 1: Summary Statistics - Sample Averages

	Contribution			Public Good		
	All Periods	Periods [6,25]	Periods [11,25]	All Periods	Periods [6,25]	Periods [11,25]
	(1)	(2)	(3)	(4)	(5)	(6)
Substitute, N=3	23.9	22.2	19.8	23.9	22.2	19.8
	(.74)	(.73)	(.76)	(.78)	(.79)	(.78)
Substitute, N=6	16.0	15.3	14.4	16.0	15.3	14.4
	(.60)	(.62)	(.67)	(.67)	(.64)	(.70)
Complements, N=3	16.5	15.6	15.1	9.2	9.6	9.5
	(.50)	(.43)	(.44)	(.43)	(.47)	(.54)
Complements, N=6	11.1	8.0	7.6	3.5	2.8	2.8
	(.72)	(.55)	(.60)	(.32)	(.18)	(.18)
Observations	1800	1440	1080	450	360	270

Standard errors in parentheses. ** p<0.01, * p<0.05, + p<0.1

Table 2: Regression Estimates

	Contribution			Public Good		
	All Periods	Periods [6,25]	Periods [11,25]	All Periods	Periods [6,25]	Periods [11,25]
	(1)	(2)	(3)	(4)	(5)	(6)
Group of 6 (β_6)	-7.87**	-6.84**	-5.47**	-7.77**	-6.73**	-5.36**
	(0.92)	(0.93)	(1.00)	(0.94)	(0.93)	(1.04)
Complementary (β_C)	-7.39**	-6.58**	-4.79**	-14.72**	-12.62**	-10.36**
	(0.87)	(0.82)	(0.87)	(0.85)	(0.88)	(0.95)
Group of 6×Complementary (β_{C6})	2.43+	-0.73	-2.03	2.01+	-0.10	-1.36
	(1.25)	(1.17)	(1.26)	(1.12)	(1.12)	(1.22)
R-squared	0.17	0.20	0.16	0.62	0.62	0.57
# Observations	1800	1440	1080	450	360	270

OLS regressions with constant and period fixed effects. Robust standard errors in parentheses.
** p<0.01, * p<0.05, + p<0.1