Electing Efficiency*

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Abstract

When every individual's effort imposes negative externalities on his competitors, competition results in excessive aggregate effort. This explains overfishing when competing on common properties, duplication in innovation tournaments, and excessive talent searches among competing sports teams. One way to curb these excesses is for subsets of competitors to form groups which share output or gross revenue. In theory, if the right number of groups forms, Nash equilibrium aggregate effort should fall to the socially optimal level. By varying the cost of investment, we investigate experimentally whether individuals manage to form the efficient number of groups and to invest within the chosen groups as theory predicts. We show that while a theory based on self interest makes correct qualitative predictions, there are systematic departures from the point predictions. We find that deviations are always in the direction of socially optimal level, which may be higher or lower than the predicted contribution level depending on the cost parameter and the group size. In terms of endogenous group formation, subjects form output-sharing groups even for the cases when theory predicts that they should not, and manage to decrease inefficiency significantly by 50% to 71%.

Keywords: Output-Sharing, Revenue-Sharing, Innovation Tournaments, Sports Contests, Common-Pool Resources, Efficient Private Provision, Free-Riding, Laboratory Experiment, Partnership Solution, Altruism

JEL Classification: L23, Q20, Q22, O13

1 Introduction

When every individual's effort imposes negative externalities on his competitors, self-interested behavior results in more aggregate effort than is socially optimal. If competitors are partitioned into output-sharing groups, their resulting free-riding should reduce aggregate effort. If groups of the right size form, all the deadweight loss can, at least in theory, be eliminated. This paper investigates in a controlled laboratory setting whether agents, given an opportunity to choose the size of their output-sharing groups, will eliminate or at least substantially reduce the inefficiencies which would otherwise occur.

In competitions to exploit common properties, aggregate effort by competing fishermen exceeds the level that maximizes aggregate profits (Dasgupta and Heal 1977)—the so-called "tragedy of the commons." Similarly, in innovation tournaments, aggregate investment by firms competing to develop the best innovation exceeds the level that would maximize their joint profits (Baye and Hoppe 2003)—the so-called "problem of R&D duplication." Moreover, in sports contests, aggregate investment by competing teams to identify and cultivate the athletic talent of their players goes beyond the level that would maximize total earnings (Canes 1974 , Dietl et al. 2008)—the so-called "problem of ruinous competition between clubs." The classic example of competing players imposing negative externalities on each other to their collective detriment is oligopoly where, as Cournot (1838) observed long ago, joint output exceeds the level that maximizes industry profits. Henceforth, we will refer to all such situations as the "negative aggregate spillover problem."

Since the negative aggregate spillover problem results in lost aggregate profits, arrangements have evolved to dampen effort incentives.[1] A common arrangement is for competitors

[1]According to anthropologists, those hunter-gatherers who have survived may have done so because their traditional practice of sharing the fish and game they caught deterred them from exhausting their resource base (Kagi 2001; Sahlins 1972).

to form groups which *share* revenue or output. Typically, effort costs are not shared because effort is too costly to monitor. Thus, as the collective work of Nobel Laureate Elinor Ostrom has documented (among others, Ostrom 1990, Ostrom and Walker 1991, and Ostrom, Gardner and Walker 1994), extractors of a common property often form groups which share whatever is extracted by any member of the group[2]. Similarly, to avoid wasteful duplication, researchers often form joint ventures and share the benefits of their discoveries within their group (Kamien et al. 1992). In the same way, college football teams share revenues within their conferences (Brown 1994) to attenuate overinvestments designed to attract fans (the upgrading of the home stadium, the search for the best coach, and the coddling of players).[3] Finally, oligopolists sometimes form revenue-sharing groups which, although competing against each other, raise prices and industry profits. This occurs at a local level within competing law partnerships and at an international level within ocean liner conferences which share gross revenues to facilitate cartelization (see Bennathan and Walters 1969).

Heintzelman et al. (2009) analyze theoretically the consequences of output sharing in an environment with negative externalities and unobservable effort. They consider a game where N self-interested players partition themselves into groups, each of which shares output but not costs. They show that although forming N solo groups (no output sharing) generates too much effort due to negative externalities and forming one group with N members generates too little effort due to free riding, socially optimal effort can be achieved (or approximated due to an integer constraint) with output sharing groups of intermediate size.

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[2]In Japan, one hundred forty-seven Japanese fisheries currently engage in output sharing. Platteau and Seki (2000) interviewed skippers in one such fishery. They concluded that "the desire to avoid the various costs of crowding while operating in attractive fishing spots appears as the main reason stated by Japanese fishermen for adopting pooling arrangements."

[3]Brown concludes that "The empirical results confirm the theoretical prediction that revenue sharing provides a disincentive to build a stronger team, other factors constant—-conferences which share more tend to have weaker teams. . . "

In this paper, we investigate whether players behave as predicted when assigned exogenously to equal-sized groups of different sizes and whether they form groups of the socially optimal size when permitted to do so.[4] In addition, we investigate whether the group size selected motivates subjects to invest efficiently.

To do this, we conduct a laboratory experiment where, for a given cost level, subjects play an investment game in a group structure that is either assigned exogenously or chosen endogenously. Throughout, we vary the cost of investment and compare predictions based on self-interest to behavior observed in the lab.

Schott et al. (2007) were the first to examine output-sharing experimentally but confined their attention to the investment behavior with an unchanged cost of investment and when subjects were assigned to groups exogenously. Schott et al. found no departures from self-interested behavior.

Establishing how subjects partition themselves endogenously is important, since, in the field, participants *choose* how many groups to form. If players turned out always to choose a suboptimal number of groups or, having chosen the optimal number of groups, turned out to invest differently than when assigned to them exogenously, then our laboratory society would never achieve efficiency even if, as in Schott et al. (2007), subjects make socially optimal choices when the optimal group structure is exogenously mandated.

In our experiments, individuals in solo groups did overinvest relative to the socially optimal level and did invest smaller amounts when in larger groups regardless of the cost of investment consistent with theoretical predictions. In one respect, however, subject behavior consistently departed from predictions. Without exception, when investment behavior was

[4]Although ours is the first paper to investigate endogenous output-sharing groups in a setting with negative externalities, the formation of groups has been investigated in public goods environments (Page, Putterman and Unel 2005; Ahn, Isaac and Salmon 2008, 2009; Brekke, Hauge, Lind and Nyborg 2009; Charness and Yang 2010).

predicted to result in inefficiency given the number of groups, subjects invested in aggregate on the socially optimal side of the Nash equilibrium. Given our experimental design, this sometimes required subjects to invest more than the Nash prediction and sometimes required them to invest less than the Nash prediction. Such apparent altruism contrasts with the Nash findings of Schott et al. but is consistent, albeit in other games, with the findings of Charness and Rabin 2002; Ostrom et. al. 1992; Ostrom et al. 1994; Ledyard 1995; Camerer 2003; Falk, Fehr and Fischbacher 2005.

When given the opportunity to *choose* the size of their groups, most of the subjects vote for the group size that is socially optimal, and subjects cut the waste associated with the negative aggregate spillover problem on average by at least two-thirds when the cost of investment is *not* high. When the cost of investment is high, subjects do not vote in accordance with theoretical predictions based on self-interest. However, the observed behavior is entirely consistent with a theory that allows for altruism.

The paper proceeds as follows: Section 2 describes our experimental design and procedures. Section 3 presents our theoretical hypotheses. Section 4 reports our experimental findings and the results of our hypothesis tests. Section 5 investigates in more depth the altruism apparent in our data. Section 6 discusses directions for future research and concludes the paper.

2 The Experiment

2.1 Design and Procedures

We conducted 25 sessions, each with a different set of 6 participants. Most participants were undergraduates at [insert university name here]. Subjects earned experimental currency (tokens), which was converted at the conclusion of the session into US dollars (1 token =

0.01 US dollars). The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). Sessions took approximately one hour and a half.

Each session was divided into six separate parts. Each of the first five parts (Parts I–V) consisted of a sequence of 5 rounds of decision making. Therefore, each subject went through 25 rounds in total. One aim of the first four parts was to give subjects experience investing as members of groups of different sizes. In Part V of the experiment, subjects *chose* the size of the groups endogenously. In Part VI, subjects completed a short questionnaire. At the end of the experiment, we randomly selected one round from each of the first five parts, added up the tokens each subject had earned in the selected rounds, converted that sum to dollars, added in the $5 show-up fee, and paid everyone. The average payment in the experiment was approximately $25 per subject.

In the first four parts, subjects were exogenously divided into groups of identical size: one-member groups, two-member groups, three-member groups, or a six-member group. Subjects were randomly rematched across groups in every round but played 5 consecutive rounds in each group size in order to gain experience. In total, there were 20 rounds in the first four parts. In order to control for order effects, the order of the first four parts was changed across sessions.

At the beginning of each decision round in the first four parts, participants were given 6 experimental tokens and had to decide how many of them $(0, 1, \ldots, 6)$ to invest in Project B. Whatever a subject did not invest in Project B was automatically invested in Project A. Denote x_{ik} as the investment in Project B by agent k in group i. Let Y_i^{-k} denote the aggregate investment in Project B by the other members of group i, X_{-i} denote the aggregate investment in Project B by other groups, and X denote the total investment in Project B by all 6 participants $(X_{-i} + Y_i^{-k} + x_{ik})$.

Project A had a fixed return of c tokens per token invested; i.e., the subject's earnings from Project A equaled c times his investment in Project A. Therefore, the "opportunity cost" of investing one additional token in Project B equaled c, the lost earnings from Project A. In the experiment, we varied this opportunity cost of investing. Note that this is a between-subjects design, i.e., each subject faces only one cost parameter.

The return per token invested in Project B, $P(X)$, was a decreasing linear function of the aggregate investment in Project B. Therefore, each token invested in Project B imposed a negative externality on everyone else–the essence of the *negative aggregate spillover* problem. For each token invested in Project B, the return from Project B was given by

$$P(X) = 200 - 5X.$$

Every member of a given group received an equal share of his or her group's return from Project B regardless of his or her own investment in that project. An individual's earnings from Project B (E_{ik}) depended on the participant's group investment in Project B and the group size (m):

$$E_{ik} = \frac{1}{m}(200 - 5X)(x_{ik} + Y_i^{-k}).$$

When there is no output sharing ($m = 1$ and $Y_i^{-k} = 0$), an individual k's earning is given by $E_i = (200 - 5[X_{-i} + x_{ik}])x_{ik}$, which is simply the return multiplied by the individual investment in Project B. This functional form is consistent with the formulation that is found in the common-property literature (Dasgupta-Heal, p. 59), the innovation-tournament literature (Baye and Hoppe, Theorem 1), and the sports-contest literature (Dietl et al. 2008, equation 2 with $\alpha = \gamma = 1$), among others.[5] In all these seemingly unrelated strategic interactions, the same game has been analyzed repeatedly in disparate literatures.[6]

[5]The same model also appears in the "rent-seeking" literature (Chung 1996, equation 2). For other literatures where this model appears, see the excellent book-length survey (Konrad 2009).

[6]In each case, player k chooses effort/investment x_k and achieves payoff $\frac{x_k}{x_k+X_{-k}}v(x_k + X_{-k}) - cx_k$ where $v(\cdot)$, the reward function, gives the value of the output or prize. When

Final earnings in each round (in tokens) were simply the sum of earnings from Project A and earnings from Project B:

$$\pi_{ik} = (6 - x_{ik})c + \frac{1}{m}(200 - 5X)(x_{ik} + Y_i^{-k}).$$

It can be seen that each individual pays the cost of his or her investment but shares the revenue equally with the members of his group.

In each of the five rounds of Part V, subjects first *voted* for one of the four group sizes. Then, subjects were divided up in groups of the size that won the most votes and played the investment game. In cases of a tied vote, the winner was chosen at random.[7]

In our experimental design, different group sizes are socially optimal under different treatments. In particular, as the opportunity cost of investing in Project B increases, the optimal group size decreases. Subjects in a given experimental session faced only one cost parameter and had to make investment decisions in all five parts of the experiment (25 rounds). A summary of the experimental design is provided in Table 1.[8] As Table 1 reflects,

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the payoff function of each player is rewritten as $x_k(P(x_k + X_{-k}) - c)$, where the strictly decreasing function $P(x_k+X_{-k}) = \frac{v(x_k+X_{-k})}{x_k+X_{-k}}$, the paternity of this ubiquitous model becomes apparent: it is the Cournot model (1838) in disguise (with x_k reinterpreted as effort instead of output). In the Cournot model, of course, the negative aggregate spillover problem results in larger industry output than a monopolist would choose. These literatures all assume that $v(\cdot)$ is strictly concave but differ in whether this function is single-peaked (as in the Cournot model) or strictly increasing (as in Baye-Hoppe 2003); the qualitative results in these literatures are unaffected by this minor difference in assumption. We chose the simpler of the two formulations as easier to explain to subjects. We assumed that $P(X)$ decreases linearly, which implies that $v(X)$ is single-peaked (a parabola).

[7]Note that in our experiment, voting is used to select group sizes and not some policy regarding the level of effort/investment. Voting is found to be useful as a tool for policy selection in common pool resources or public goods literature (Walker, Gardner, Herr and Ostrom 2000, Tyran and Feld 2006, Putterman, Tyran and Kamei 2010).

[8]Order of the group sizes has been changed across sessions. The following explains the

the socially optimal group size is different for each treatment. For example, for opportunity cost $c = 20$, the optimal size of each group is 3 members (or, equivalently, the optimal number of groups is 2).

Table 1: Experimental Design

Cost parameter *c*	Efficient group size	Parts I – IV	Part V	Number of sessions	Number of subjects
1	6	Exogenous	Voting	5	30
20	3	Exogenous	Voting	5	30
55	2	Exogenous	Voting	5	30
100	1	Exogenous	Voting	5	30

Prior to the experiment, a test was administered to the subjects to make sure they understood the payoff consequences of their choices. The computer prevented anyone from beginning the session until *everyone* had a perfect score on the test.

During the experiment, subjects could either calculate their payoffs by hand or could utilize a "Situation Analyzer" provided to facilitate their calculations. A subject could enter his or her conjecture about (1) the total investment in Project B by others *inside* his or her group and (2) the total investment in Project B by subjects *outside* his or her group. The Situation Analyzer would then provide a table listing in one row the seven choices for investing in Project B ($0, 1, \ldots, 6$ tokens) and in the other row the total payoff from the two projects that the subject would earn if his or her two conjectures were accurate. Subjects were free to do such calculations by hand or to use the Situation Analyzer as often as they wanted before making a decision. The Situation Analyzer is shown in Figure 1.

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order of the group sizes for each cost treatment. We ran 1236, 6312, 2163, 3621 and 1623 for $c = 1$; 1236, 3261, 6312, 2163 and 6231 for $c = 20$; 1236, 3621, 2163, 6312, and 1623 for $c = 55$; 1236, 6312, 2163, 3261 and 6132 for $c = 100$. Note that in each case the socially optimal group size has been presented at each location at least once.

Figure 1: Situation Analyzer for Groups of Two

If the total investment by others outside your group in Project B is 12

If the total investment by others inside your group in Project B is 4

Analyze this situation

Your investment in B	0	1	2	3	4	5	6
Your earnings (A + B)	840.0	787.5	730.0	667.5	600.0	527.5	450.0

To further help subjects to make a decision at a given round (all 25 rounds), a table with a history of play is provided. Subjects were reminded of their own investments, others' investments in their group, and the total investment, as well as their earnings from previous rounds.

After the session, we administered a short questionnaire. We asked subjects the basis of their investment decisions and the basis of their vote on group size. Responses clearly showed that subjects understood the experiment. Most of the subjects reported that they tried to maximize their monetary earnings.

3 Theoretical Predictions and Hypotheses

Theoretical predictions are based on Heintzelman et al. (2009). Given the size of each group and the opportunity cost of investing in Project B, every individual simultaneously invests to maximize his or her own payoff from the two projects. Proposition 1 summarizes the mean investment in Project B in the Nash equilibrium.

Proposition 1. For a given opportunity cost (c) and group size (m), mean investment in

Project B is $\bar{x} = \frac{200-cm}{30+5m}$.[9]

We use this formula to calculate the mean equilibrium investment in Table 2 for each of the 16 group size-cost combinations in the various experimental treatments. For any opportunity cost (c), note that Nash equilibrium investment in Project B decreases with the size of each group and that, for any group size (m), investment also decreases with the opportunity cost.

Proposition 2 summarizes the mean investment in Project B that would maximize the aggregate revenue from the two projects. We refer to this as the "socially efficient investment level" and denote it x^*. It is simply 1/6 of the aggregate investment that maximizes $XP(X)+ (36-X)c$.

Proposition 2. To maximize social surplus, mean investment in Project B must be $x^* = \frac{200-c}{60}$.

This formula is used to calculate the socially efficient levels in the last row of Table 2. Note that as the opportunity cost rises, the socially efficient investment level falls.

Equilibrium investment in Project B exceeds the socially optimal level when no one shares (one-person groups) and falls short of the socially optimal level when everyone shares (six-person group). Moreover, as the group size increases from one to six, aggregate investment in Project B declines monotonically. There is, therefore, a unique real number m (not necessarily an integer) which induces mean investment in the Nash equilibrium ($\bar{x}$) to equal socially efficient investment (x^*). When the integer constraint is respected, one of the six group sizes will generate a larger social surplus in the Nash equilibrium than any other group size and is predicted to increase efficiency close to the socially optimal level. We refer to this group size as the "partnership solution" (Heintzelman et al. (2009)). Note that

[9]Total investment within each group is uniquely determined in the equilibrium, but not the investment of individual members of a group. Therefore, we focus on the mean investment level. See Heintzelman et al. (2009) for more details.

the partnership solution is a self-enforcing mechanism that requires neither monitoring of individual behavior nor intervention of the government.

In Table 2, in every cost column there is a shaded entry. The associated row is the partnership solution for that particular opportunity cost. The shaded entry is the Nash equilibrium mean investment in Project B for that opportunity cost.[10]

Table 2: Nash Equilibrium Mean Investment in Project B

Group size	Cost = 1	Cost = 20	Cost = 55	Cost = 100
1	5.69	5.14	4.14	2.86
2	4.95	4	2.25	0
3	4.38	3.11	0.78	0
6	3.23	1.33	0	0
	Socially efficient level = 3.32	Socially efficient level = 3	Socially efficient level = 2.42	Socially efficient level = 1.67

Proposition 3 follows from the definition of the partnership solution:

Proposition 3. For a given opportunity cost (c), every individual strictly prefers the partnership solution to any other group size.

The partnership solution is the Condorcet winner, because it would be chosen unanimously if every subject voted for the group size he most preferred. Of course, as in many voting games, inferior alternatives can also be supported as Nash equilibria since if everyone expects

[10]In this experiment, subjects faced a discrete action space. Though the theoretical predictions were generated from a game with continuous actions, the assumption of discrete actions does not change the predictions. More specifically, suppose agents choose a noninteger investment level x for Project B in the symmetric equilibrium of the continuous investment game. Then, in the discrete version, there is an equilibrium in which every player chooses the integer above x or below x, or mixes between the two. As a result, both the actions and the payoffs in the discrete and continuous versions are very similar.

that everyone else is voting for the same alternative, then no one can change the outcome by deviating unilalterally. However, these spurious Nash equilibria can be eliminated by iterative elimination of weakly dominated strategies. The partnership solution would then be predicted to receive the most votes.[11]

In this paper, we test the following hypotheses as well as the point predictions presented in Table 2:

Hypothesis 1. For a given opportunity cost (c) of investing in Project B, mean investment in that project strictly decreases with the size of the groups.

Hypothesis 2. Mean investment in Project B decreases with the opportunity cost of investing in that project for a given group size.

Hypothesis 3. Subjects will "elect efficiency"—they will vote for the group size predicted to generate the largest social surplus in the Nash equilibrium.

The experimental data and findings are presented in the next section.

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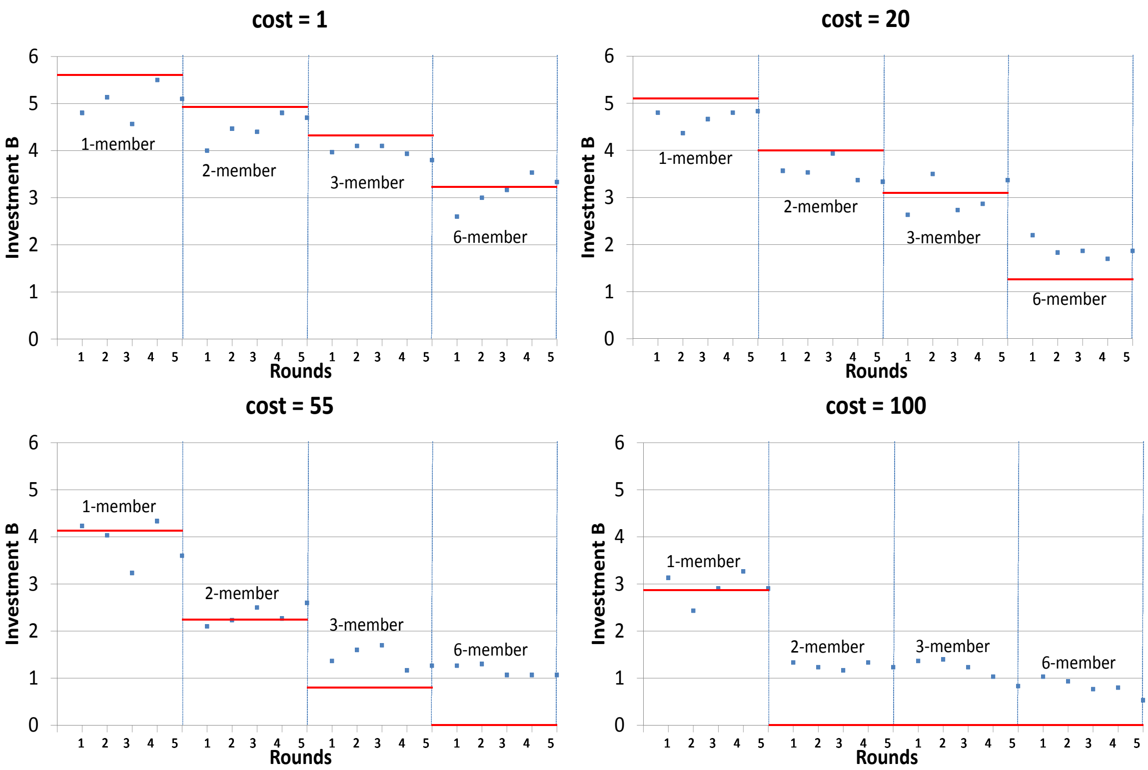
[11]We piloted a second voting mechanism which needs no such refinement since its Nash equilibrium is unique: after each subject had voted in the pilot, one of the six subjects was randomly chosen to be "dictator," and his or her vote determined the partnership structure. Since every subject anticipated being chosen as the dictator with positive probability, each subject should have been motivated to vote for his or her most preferred alternative. However, we were unable to distinguish behavior under the two voting schemes. Hence, we used the more familiar nondictatorial scheme for this paper.

4 Data Analysis

4.1 Exogenous Groups and Investment Decisions

Figure 2 shows the average investment corresponding to each opportunity cost parameter in the first 20 rounds (Parts I–IV). Horizontal lines represent the theoretical predictions. For simplicity, group sizes are presented in the following order: one-member, two-member, three-member, and six-member groups, although orders were randomized during the sessions.[12] Consistent with the theoretical predictions, contributions decrease with the group size for any cost level.

Figure 2: Mean Investment



Theoretical predictions and the observed mean levels of investment in Project B are

[12]We do not observe any order effects in our data.

provided in Table 3. Theory predicts that the socially optimal group size decreases with cost. Observed mean investment and predicted investment in Project B are shaded for the theoretically optimal group sizes. Observed mean investment at the optimal group size for each cost is surprisingly close to the theoretical predictions and the socially optimal level of investment.

Table 3: Predicted versus Observed Mean Investment

	c = 1		c = 20		c = 55		c = 100	
Group size	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed
1	5.69	5.02 (1.36)	5.14	4.69 (1.55)	4.14	3.89 (1.50)	2.86	2.93 (1.70)
2	4.95	4.47 (1.41)	4	3.55 (1.54)	2.25	2.34 (1.68)	0	1.26 (1.38)
3	4.38	3.98 (1.55)	3.11	3.02 (1.56)	0.78	1.42 (1.35)	0	1.17 (1.46)
6	3.23	3.13 (1.85)	1.33	1.89 (1.59)	0	1.15 (1.47)	0	0.81 (1.12)
	Socially efficient investment = 3.32		Socially efficient investment = 3		Socially efficient investment = 2.42		Socially efficient investment = 1.67	
Standard deviations are in parentheses Number of observations = 150 per cell								

We performed some nonparametric tests by using independent observations (one data point per session). One-sided sign tests confirm that there are no significant differences between the observed levels of investment and the theoretical predictions at the optimal group sizes ($p - values > 0.1$). For nonoptimal group sizes, point predictions do not hold in general (p-values are generally less than 0.05).[13] However, all deviations are toward the socially optimal level.

[13] The two exceptions are when cost is 20 and group size is six and when cost is 55 and group size is one. In these cases, investments are not significantly different than the predicted levels.

Result 1: *Theoretical predictions are supported at the optimal group sizes. However, there are deviations from quantitative predictions for other group sizes. When data are not consistent with the predicted levels, deviations are in the direction of socially optimal level in all cases.*

Table 4 shows the observed mean payoff for each cost and group size. For cost levels $c = \{1, 20, 55\}$ theoretically predicted optimal group size generates the highest level of payoff. Note that for $c = 100$ theoretically predicted optimal group size is 1 (no output sharing). However, for $c = 100$, higher levels of payoff are achieved with group sizes more than 1. One possible explanation is that, as Table 3 shows, theoretically predicted level of investment is not very close to the socially efficient level (since it is not possible to divide individuals into noninteger group sizes). Even though the mean investment with solo groups is not significantly different than predicted, the deviations we observe in the other group sizes affect the payoffs in an unpredicted way.[14]

Table 4: Predicted versus Observed Mean Payoff

	c = 1		c = 20		c = 55		c = 100	
Group size	Predicted payoff	Obs. ave. payoff	Predicted payoff	Obs. ave. payoff	Predicted payoff	Obs. ave. payoff	Predicted payoff	Obs. ave. payoff
1	168	241 (88.03)	252	295 (90.61)	416	427 (75.65)	640	625 (61.61)
2	256	286 (75.70)	360	370 (67.48)	504	497 (101.21)	600	670 (109.19)
3	302	314 (58.25)	390	377 (64.86)	425	465 (85.11)	600	671 (132.10)
6	336	323 (22.34)	307	341 (48.99)	330	443 (88.00)	600	656 (105.90)
	Socially efficient payoff = 336		Socially efficient payoff = 390		Socially efficient payoff = 505		Socially efficient payoff = 683	
Standard deviations are in parentheses Number of observations = 150 per cell								

[14]For group sizes greater than 1, complete free riding is not observed as predicted. This is consistent with behavior observed in public goods experiments. It has been documented that subjects do not free ride completely (see Ledyard 1995).

For cost levels $c = \{1, 20, 55\}$, we test whether the Partnership Solution improves the payoff of participants relative to the case where there is no output sharing (being solo). By using matched-pair sign-rank tests, we confirm that the Partnership Solution increases the payoffs. In particular, we compare the mean payoff levels at the socially optimal group size with the mean payoff levels at the group size of one. Each individual's payoff increases with the Partnership Solution and the difference is significant at the 5% level.

For $c = 100$, the group size of 1 brings the lowest payoff, even though it was the theoretically optimal group size (p-values for all pairwise comparisons are 0.04). Output sharing seems to help individuals even in situations where theoretically it is not the case.

Result 2: *Output sharing improves payoffs (compared to being solo) when groups are exogenously formed.*

We complement nonparametric tests with a regression analysis. We investigate the impact of different group sizes, costs, the order of presenting group sizes, and rounds on individual investment decisions by running ordinary least squares estimation with robust standard errors (see Table 5).[15]

Regression results (specification 1) show that for a given cost level, an increase in the group size decreases the level of investment in Project B. We also see that there is a negative relationship between the level of investment and the opportunity cost parameter, c. Specifications 2–4 show that these results continue to hold even when we add control variables or when we include the different treatments as dummy variables.[16] In addition, we see that the

[15]Data are clustered by 20 sessions.

[16]We find that the coefficient of grsize2 is significantly smaller than the coefficient of grsize3, and the coefficient of grsize3 is significantly smaller than the coefficient of grsize6 ($p - values < 0.01$). We find the same result for cost parameters as well.

Table 5: Ordinary Least Squares Results

Dependent var: Investment B	1	2	3	4
groupsize	−0.42**	−0.42**	−0.43**	
	(0.02)	(0.02)	(0.02)	
cost	−0.03**	−0.03**	−0.03**	
	(0.00)	(0.00)	(0.00)	
round		0.00	0.00	
		(0.02)	(0.02)	
grsize2				−1.23**
				(0.12)
grsize3				−1.74**
				(0.14)
grsize6				−2.39**
				(0.13)
cost20				−0.86**
				(0.12)
cost55				−1.95**
				(0.11)
cost100				−2.61**
				(0.09)
round2				0.04
				(0.10)
round3				−0.03
				(0.09)
round4				0.09
				(0.10)
round5				−0.00
				(0.10)
phase2			−0.10	−0.00
			(0.17)	(0.10)
phase3			−0.01	0.08
			(0.18)	(0.12)
phase4			−0.08	0.02
			(0.23)	(0.14)
Constant	5.20**	5.19**	5.25**	5.45**
	(0.10)	(0.09)	(0.16)	(0.16)
Observations	2,400	2,400	2,400	2,400
R-squared	0.384	0.384	0.384	0.431

Robust standard errors in parentheses
** p < 0.01, * p < 0.05

order of treatments and experience do not affect investment decisions.[17] In summary, one cannot reject hypotheses 1 and 2. Our results are robust to different estimation methods.[18]

Result 3: *The data are consistent with the (qualitative) theoretical predictions. For each cost level, investment decreases with group size. Moreover, investment decreases with cost for a given group size.*

4.2 Voting for Group Size: The Plurality Rule

Table 6 presents the percentage of votes that each group size received for each cost level. There are 150 observations for a given level of cost. Except for $c = 100$, groups frequently vote for the theoretically predicted optimal group size. Approximately 60% of the votes are socially optimal for $c = \{1, 55\}$, and approximately 40% of the votes are socially optimal for $c = 20$.

Table 6: Percentage of Votes in Part V

Group size	c = 1	c = 20	c = 55	c = 100
1	8	12.7	7.3	22
2	16	39.3	57.3	24.7
3	16.7	39.3	11.3	33.3
6	59.3	8.7	24	20

For each cost parameter, we test whether one can reject the null hypothesis that the proportion of votes is 25% for each group size. For $c = \{1, 20, 55\}$, one can strongly reject this null hypothesis (chi-square goodness of fit test, $p - values < 0.01$). For $c = 100$, one

[17]Note that the variable round takes values $1, 2, ..., 5$.

[18]For robustness checks, we have also conducted fixed-effect regressions both at the individual and at the session levels. Group size affects investment negatively for all cost levels. In addition, round seems to have a small but significantly negative effect for cost levels greater than 1. Results are available upon request.

cannot reject that the proportion of votes is 25% for each group size ($p - value = 0.10$). More important, when the cost of investing is not very high, the highest percentage of votes is for the socially optimal group sizes. In particular, for $c = 1$, group size 6 received the highest number of votes; for $c = 20$, group sizes 2 and 3 received the highest number of votes; and for $c = 55$, group size 2 received the highest number of votes (proportion tests, $p - values < 0.01$). For $c = 100$, group size 3 received significantly more votes than the socially optimal level of one (proportion test, $p - value = 0.049$).

Result 4: *For $c = \{1, 20, 55\}$, the highest proportion of votes is received by the corresponding socially optimal group sizes. (This holds weakly for $c = 20$.)*

Result 4 shows that participants choose to form output-sharing groups for all cost levels including $c = 100$ when theory predicted subjects would vote for solo groups. In all cases, majority of the votes corresponds to the group size which have generated the highest average payoff in the first four parts of the experiment. Out of 600 possible cases, subjects voted for the group size that generated the highest average payoff 248 times.[19] In addition, we conduct a multinomial logit regression analysis to test whether votes are significantly affected by cost, previous earnings and experience.[20] We construct a new variable, bestgroup, which takes value 1, 2, 3 if a subject earned the most money in Parts I–IV when the group size is 1, 2, 3, respectively, and takes value 4 if a subject earned the most money when the group size is 6.[21] Similarly, we construct a variable named vote, which takes values 1, 2, 3 and 4 when the voted group size is 1, 2, 3 and 6, respectively. We regress votes on cost, bestgroup

[19]Therefore, 352 votes are for group sizes that have not generated the highest payoff. 95 out of these 352 votes are for the socially optimal group sizes.

[20]Since utilities from different group sizes do not need to be ordered, a multinomial logit regression analysis is more suitable than an ordered logit regression analysis. In addition, we have performed OLS regressions, and qualitative results do not change.

[21]The earnings in each part are calculated by adding up each payoff from the 5 corresponding rounds.

and round (which takes values 1,2,3,4 and 5).[22] Regressors are jointly significant at the 0.05 level (Wald chi-square = 74.93, $p - value < 0.01$). In addition, we find that both cost and bestgroup significantly affect votes (Wald tests, $p - value = 0.03$ and $p - value < 0.01$ respectively). However, coefficient estimates of round are not jointly statistically significant ($p - value = 0.40$).

Table 7 presents the marginal effects after a multinomial logit regression. Robust standard errors are provided in parentheses.

Table 7: Multinomial Logit Regression – Marginal Effects

	Dependent variable = vote			
VARIABLES	Group size = 1	Group size = 2	Group size = 3	Group size = 6
cost	0.001	-0.000	0.001	-0.002*
	(0.001)	(0.001)	(0.001)	(0.001)
bestgroup	-0.037	-0.266**	0.059	0.245**
	(0.034)	(0.052)	(0.036)	(0.032)
round	0.007	0.005	-0.023	0.011
	(0.011)	(0.012)	(0.013)	(0.017)
Observations	600	600	600	600

Robust standard errors in parentheses
** p < 0.01, * p < 0.05

We see that the probability of voting for group size 6 significantly decreases with cost and increases with bestgroup, whereas the probability of voting for group size 2 decreases with bestgroup.[23] These findings are consistent with the theoretical predictions. A simple correlation analysis also confirms that votes are negatively correlated with cost (–0.21) and positively correlated with bestgroup (0.46).

[22]The variables cost and bestgroup are not highly correlated. The correlation between cost and bestgroup is only -0.21.

[23]Since bestgroup is a discrete variable, we have also looked at the predicted probabilities for each group size under each possible value of bestgroup. We have observed similar results.

Result 5: *Votes are affected by both the cost parameter and the previous earnings at different group sizes. Votes do not change significantly as subjects get more experienced with voting.*

Table 8 presents the voting outcomes, mean investment decisions and payoffs conditional on the chosen group size.[24] As in the exogenous groups, we see that participants choose investment levels that are consistent with the theoretical predictions at the socially optimal group sizes (all p-values are greater than 0.27).[25] Moreover, qualitative results are similar to the case when groups are exogenously imposed: investment decreases with the group size ($p - value < 0.01$) and cost ($p - value < 0.01$). Regression results are available from the authors.

Result 6: *Mean investment levels in Part V are not significantly different than theoretically predicted levels at the socially optimal group sizes. In addition, investments are consistent with the (qualitative) theoretical predictions. Investment decreases with group size and cost.*

Finally, we compare the efficiency of endogenous group formation with the case of exogenous groups. Efficiency of each part is defined by the observed average payoff divided by socially optimal payoff. In Table 9, we provide the efficiency levels in all parts for each cost treatment. As expected, efficiency levels are quite large. Endogenous group formation increases efficiency compared with the case of no output sharing for all cost levels. In particular, efficiency loss decreased by 50% for $cost = 100$ and by 68% to 71% for the other cost levels.[26] Tables 6 and 9 together show that subjects do vote for efficient outcomes.

[24]Since ties are broken randomly, even though there are equal number of votes for group sizes 2 and 3 when cost is 20, group size 2 won the voting more frequently than group size 3.

[25]We focus on the socially optimal group size, since votes are more often for the optimal group size. Therefore, there are not too much data available on the other group sizes. In fact, there are too few data points for many of the nonoptimal group sizes, which makes statistical testing not very meaningful.

[26]The efficiency levels are quite high considering the fact that voting part has been per-

Table 8: Mean Investment and Payoff Conditional on Chosen Group Size

c	Group size	Frequency (out of 25)	Investment		Payoff	
			Predicted	Observed	Predicted	Observed
c = 1	1	2	5.69	5.75 (0.62)	168	158 (21.45)
	2	2	4.95	4.67 (1.23)	256	278 (53.76)
	3	1	4.38	4.50 (1.22)	302	294 (58.43)
	6	20	3.23	3.26 (1.71)	336	323 (20.82)
			Predicted	Observed	Predicted	Observed
c = 20	1	3	5.14	4.89 (1.49)	252	266 (102.95)
	2	12	4.00	3.74 (1.65)	360	369 (86.64)
	3	10	3.11	3.00 (1.28)	390	383 (48.70)
	6	0	1.33	–	307	–
			Predicted	Observed	Predicted	Observed
c = 55	1	0	4.14	–	416	–
	2	18	2.25	2.20 (1.37)	504	498 (88.20)
	3	1	0.78	0.83 (0.98)	425	430 (57.47)
	6	6	0	1.11 (1.69)	330	442 (95.41)
			Predicted	Observed	Predicted	Observed
c = 100	1	7	2.86	2.67 (1.51)	640	648 (39.62)
	2	6	0	1.00 (1.39)	600	659 (111.82)
	3	11	0	0.85 (1.18)	600	661 (105.97)
	6	1	0	0.50 (0.83)	600	643 (83.67)

For example, for $cost = 100$, Table 6 shows that subjects are not choosing the theoretically predicted group size but instead vote for group sizes 2 and 3.[27] Table 9 shows that by doing so, they are actually achieving higher payoffs/efficiency.

Table 9: A Comparison of Efficiency Levels

	Group size	c = 1	c = 20	c = 55	c = 100
Exogenous	1	0.72	0.76	0.84	0.92
	2	0.85	0.95	0.98	0.98
	3	0.93	0.97	0.92	0.98
	6	0.96	0.87	0.88	0.96
Endogenous	voting	0.91	0.93	0.95	0.96

Result 7: *Subjects cut the inefficiency by one-half when cost* $= 100$ *and by at least two-thirds in the remaining cost treatments.*

5 Discussion

As previously noted, whenever aggregate investment in the Nash equilibrium differs substantially from socially optimal aggregate investment, our subjects deviated from our Nash prediction in the direction of socially optimal investment.

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formed at the very last stage of the experiment, since as public goods literature has consistently showed free riding increases over periods.

[27]Note that since group size can only be an integer, theoretically predicted socially optimal group size does not imply that highest possible level of efficiency will be reached at that group size. It only implies, given selfish individuals, this predicted group size will bring higher efficiency compared to other group sizes. While for $cost = 1, 20, 55$ data are consistent with this prediction, for $cost = 100$, higher efficiency is reached for group size of 3. As Table 2 shows the gap between the Nash equilibrium investment level at the socially optimal group size and the socially optimal investment level is highest for $cost = 100$. This explains why higher levels of payoffs are reached at $cost = 100$ compared to the predicted payoff of 640 (see Table 8), but not at the other cost levels.

To investigate this behavior in more depth, we utilize our Situation Analyzer. We examine the last pair of conjectures entered by each subject before making an investment decision in a given period. We calculate the proportion of times subjects best-responded to their conjectures and the proportion of times that they deviated so that the sum of the payoffs of the other five subjects increased even more than their own payoff decreased.[28] We find that approximately 37 percent of the times subjects invested after using the Situation Analyzer their decisions are self-interested (best) responses to their conjectures and approximately 20 percent of the times the decisions are altruistic.[29]

The percentage of investments which are best responses significantly increases over the periods ($p - value = 0.039$), while the percentage of investments which are altruistic does not decrease over the periods ($p - value = 0.777$).[30] One should be cautious in interpreting these results since (1) in 798 of the 3000 investment decisions we observe, subjects declined to use the Situation Analyzer before entering their investment decision and (2) subjects had no direct financial incentive to input their actual conjectures. Nonetheless, these data seem to provide some insight into the observed behavior.

To project whether this apparent altruism would ultimately disappear, we perform a convergence analysis. For each cost and group size, we run a simple linear regression analysis to estimate asymptotic investment behavior.[31] Both initial and long term (asymptotic)

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[28]Another possibility is to consider the average of the conjectures as the real conjecture of the subjects. Our results do not change with this different specification.

[29]A deviation is considered to be altruistic if by deviating the subject is increasing the total payoff of all 6 subjects in the session at a cost to themselves. The percentages for altruistic behavior would be higher if we instead consider a deviation to be altruistic when by deviating a subject increases others' payoff (not including himself).

[30]We only consider the first 20 periods since in the last part of the experiment subjects choose the optimal group size the most and therefore, the role of altruism is very limited. When cost=100, subjects do not vote for the theoretically optimal group size, and therefore, we actually see an increase in the altruistic decisions (30 percent).

[31]We run the following specification:

estimates for investments are provided in Table 10. Except for the group sizes that are socially optimal for a given cost, in most of the cases asymptotic estimates are significantly different than the predicted levels and closer to the socially optimal investment levels. This implies that one should expect deviations from the theoretical predictions towards altruistic outcomes.

In contrast to these findings, Schott et al. (2007) reported no systematic departures from self-interested behavior. Perhaps the difference in our results arises because we had fewer subjects per session (6 subjects instead of 12 subjects) or because we explored a range of cost parameters while they confined themselves to a single cost parameter (outside of our range). However, altruism has been used to explain departures from Nash predictions in prisoner dilemma experiments, dictator experiments, common property experiments, and public goods experiments, among others (for an overview of altruism in experiments, see Andreoni, Harbaugh, and Vesterlund 2008; see also Ostrom et al. 1994; Ledyard 1995; Charness and Rabin 2002).

In the dictator game, a selfish dictator would contribute nothing to the other player. In the linear public goods game, selfish players would make no contributions to the public account. Positive contributions in either game are interpreted as altruism but, as Ledyard (1995) pointed out, all errors in such games must lie on the side of the Nash prediction interpreted as altruism. In contrast, aggregate investment motivated by altruism in our experiment is predicted to be larger than aggregate investment motivated by self-interest for some sets of parameters (the number of groups and the cost of investing) but smaller than self-interested investment for other sets of parameters. This makes it all the more remarkable

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$investment_i = \alpha(\frac{1}{t}) + \beta(\frac{t-1}{t}) + \epsilon_i$

where i indicates observations and t represents the period number. Notice that as t gets larger $(\frac{1}{t})$ approaches zero, and $(\frac{t-1}{t})$ approaches 1. Hence, the constant β gives the asymptotic estimate of investment, and the constant α gives an estimate for the initial investment.

Table 10: Initial versus Asymptotic Estimates

	Group size	Average	Initial Point	Asymptote	Predicted
c = 1	1	5.02	4.98 (0.11)	5.10*** (0.12)	5.69
	2	4.47	4.04 (0.17)	4.57* (0.16)	4.95
	3	3.98	3.43 (0.11)	4.10 (0.13)	4.38
	6	3.13	2.41 (0.13)	3.28 (0.04)	3.23
c = 20	Group size	Average	Initial Point	Asymptote	Predicted
	1	4.69	4.48 (0.15)	4.75* (0.15)	5.14
	2	3.55	2.44 (0.10)	3.79** (0.07)	4.00
	3	3.02	2.01 (0.08)	3.16 (0.14)	3.11
	6	1.89	2.59 (0.45)	1.69 (0.20)	1.33
c = 55	Group size	Average	Initial Point	Asymptote	Predicted
	1	3.89	4.09 (0.64)	3.83* (0.13)	4.14
	2	2.34	2.97 (0.06)	2.20 (0.08)	2.25
	3	1.42	0.75 (0.18)	1.51*** (0.11)	0.78
	6	1.15	1.32 (0.20)	1.11** (0.28)	0
c = 100	Group size	Average	Initial Point	Asymptote	Predicted
	1	2.93	2.23 (0.09)	2.98 (0.07)	2.86
	2	1.26	1.11 (0.10)	1.23*** (0.17)	0
	3	1.17	1.35 (0.17)	1.03*** (0.05)	0
	6	0.81	1.57 (0.24)	0.59*** (0.89)	0

Robust standard errors clustered at the session level are provided in parenthesis.
***Significantly different than the predicted investment at 1% level, **at 5% level, *at 10% level.

that *every* departure from Nash equilibrium that we observe is in the direction of socially efficient aggregate investment.

6 Conclusions

When every individual's effort imposes negative externalities on his competitors, competition results in excessive aggregate effort. This explains overfishing when competing on common properties, duplication in innovation tournaments, and excessive talent searches among competing sports teams. In theory, one way to curb these excesses is for subsets of competitors to form groups which share output or revenue. If the right number of groups forms, Nash equilibrium aggregate effort should fall to the socially optimal level.

In this paper, we investigate whether players behave as predicted when assigned exogenously to equal-sized groups of different sizes and whether they form groups of the socially optimal size when permitted to do so. In addition, we investigate whether the group size selected motivates subjects to invest efficiently. We find that output sharing attenuates the negative aggregate spillover problem *regardless* of the opportunity cost of investing. Consistent with theoretical predictions, we find a negative relationship between the aggregate investment levels and group size. For a given group size, we show that aggregate investment decreases as the opportunity cost of investing in it increases. Surprisingly, we show that given the opportunity to form groups endogenously, subjects choose output-sharing groups even when a theory based on self-interest predicts solo groups. The underlying cause of this is the fact that theory based on self-interest does not predict aggregate investment well when Nash investment and socially optimal investment are significantly different. In such cases, deviations from equilibrium predictions are without exception in the direction of socially efficient aggregate investment.[32] One explanation for this is that individuals are altruistic.

[32]This is based on the investment data from the exogenous groups since there are very few

If individuals care not only about themselves but also about others, then one would expect to see higher levels of efficiency than predicted by a theory predicated on the assumption of self-interested behavior. This is highly consistent with our experimental data for the investment stage. In addition, altruism explains why subjects vote to have partners even when the cost of investment is so high that we predicted they would choose to go solo. Based on their experience in exogenously formed groups subjects anticipated that there would be less free riding in the investment stage than would occur if every subject were self-interested. As a result, solo groups were no longer their best option. In sum, what started out as a "mere" test of the theory has ended up showing that there are systematic departures from self-interested behavior. By documenting these and the experiment in which they arise, we provide data which a future theory of behavior must admit as possible predicted outcomes if it is not to be rejected.

Future research should address the stability of the partnership mechanism and its sensitivity to inter-subject communication. By stability, we mean migrations of subjects from one existing group to another or from an existing group to a newly formed group.[33] The effect of inter-subject communication on the Partnership Solution is the subject of a recent study by Buckley et al. (2009, 2010). They find that when individuals within the same output-sharing group are able to communicate, free riding decreases. It is unclear from their work whether similar results would occur if subjects collectively *chose* their group size; moreover, communication may affect the choice of group size itself. We leave the investigation of such

data points for statistical testing for endogenous groups at the nonoptimal group sizes.

[33]After the voting stage but before the investment stage, a migration stage could be inserted. Subjects could be permitted to migrate simultaneously from the group to which they are assigned after the voting stage to another group of their choosing. Heintzelman et al. (2009) predict that no such migrations should occur. However, they also predict that migrations to newly formed solo partnerships would occur *unless* there was a direct cost to such migrations or there was a benefit to team production which would be lost by going solo. We plan to test these predictions in future work.

interplay between communication and endogeneity to future research.

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