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Size Matters (in Output-Sharing Groups): Voting to End the Tragedy of the Commons

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Size Matters (in Output-Sharing Groups): Voting to End the Tragedy of the Commons*

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Abstract

Individuals extracting common-pool resources in the field sometimes form output-sharing groups to avoid costs of crowding. In theory, if the right number of groups forms, Nash equilibrium aggregate effort should fall to the socially optimal level. Whether individuals manage to form the efficient number of groups and to invest within the chosen groups as theory predicts, however, has not been previously determined. We investigate these questions experimentally. We find that subjects do vote in most cases to divide themselves into the optimal number of output-sharing groups, and in addition do decrease the inefficiency significantly (by 50% to 71%). We did observe systematic departures from the theory when the group sizes are not predicted to induce socially optimal investment. Without exception these are in the direction of the socially optimal investment, confirming the tendency noted elsewhere in public goods experiments for subjects to be more "other-regarding" than purely selfish.

Keywords: Catch-Sharing, Common-Pool Resources, Efficient Private Provision, Free-Riding, Laboratory Experiment, Partnership Solution

JEL Classification: L23, Q20, Q22, O13

1 Introduction

The common-property problem results in excessive mining, hunting, and extraction of oil and water. The same phenomenon is also responsible for excessive investment in research and excessive outlays in rent-seeking contests. As the collective work of Nobel Laureate Elinor Ostrom extensively documents, however, humans sometimes find creative solutions to eliminate or mitigate the ubiquitous common-property problem (Ostrom 1990; Ostrom and Walker 1991; Ostrom, Gardner, and Walker 1994; Poteete, Janssen, and Ostrom 2010). One such mechanism is output-sharing (Schott, 2001; Heintzelman, Salant, Schott 2009). This paper investigates in a controlled laboratory setting whether agents, given an opportunity to choose the size of their output-sharing groups, can eliminate or at least attenuate the common-property problem.

Heintzelman et al. (2009) have recently analyzed the consequences of output sharing in an environment with negative externalities and unobservable effort. They consider a game where N self-interested members of output-sharing groups simultaneously choose their fishing efforts. Every individual is assumed to pay his or her own effort cost, since effort is unobservable. The polar case where every partnership contains a single individual (N such partnerships in all) corresponds to the standard formulation of the common-property problem and is well known to result in excessive aggregate effort. As the N players are partitioned into fewer but larger partnerships, aggregate effort in the Nash equilibrium falls monotonically until the other polar extreme is reached where all N players are grouped into one grand output-sharing partnership. However, aggregate effort in that configuration is *below* the social optimum.[1] To maximize social surplus and eliminate the common-property problem requires an *intermediate* number of groups. Heintzelman et al. (2009) refer to the

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[1] Although every player receives $1/N^{th}$ of the marginal social benefit of increasing his effort one unit, he incurs the entire marginal social cost of his increased effort, and hence he would have an incentive to reduce his effort below $1/N^{th}$ of the socially optimal level.

partnership structure maximizing social surplus as the "Partnership Solution." Note that the Partnership Solution is a self-enforcing mechanism that requires neither monitoring of individual behavior nor intervention of the government.

Some societies seem to have hit upon this solution long ago. In Japanese fisheries, fishermen within a group of vessels share their catches. Their pooled output is sold through a common outlet, and each group member receives an equal share of his partnership's gross revenue, no matter how little effort he has expended. One hundred forty-seven Japanese fisheries engage in output sharing in spite of—or because of—the free riding involved. Platteau and Seki (2000) interviewed skippers in one such fishery, the glass-shrimp industry, to determine their motivation. The researchers were surprised to find that the fishermen never mentioned ensuring against low catches as one of the motivations for forming output-sharing partnerships. Instead, Platteau and Seki 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."

These Japanese fishermen appear to have rediscovered an ancient solution to the common-property problem. According to anthropologists, those hunter-gatherer cultures that have survived to modern times may owe their success to their practice of sharing the fish and game caught by groups of hunters, since extensive sharing dulls hunting effort sufficiently to protect common property from overexploitation (Kagi 2001; Sahlins 1972).

At the opposite end of the technological spectrum, individuals who form research joint ventures to share revenue from their discoveries may have hit upon the same solution. When an increase in aggregate research activity would raise the expected value of the best innovation, competition among individuals to discover and patent the best innovation will result in too much research (Baye and Hoppe 2003) and forming competing research joint ventures can restore the social optimum (Heintelzman et al. 2009).

Schott et al. (2007) were the first to examine output sharing experimentally by exogenously dividing subjects into equal-size groups. They demonstrated that exogenous variations in group size affect subsequent behavior as predicted and that the appropriate exogenous group size results in socially optimal behavior.

We build on their work by addressing several important questions that they were unable to explore in their pioneering study. We investigate whether, given the opportunity, individuals will *choose* to form output-sharing groups of equal size instead of everyone remaining solo.[2] In addition, we investigate whether the output-sharing groups that subjects choose motivate them to invest more efficiently than they would when operating solo. To do this, we conduct a laboratory experiment where subjects vote on the size of their output-sharing groups and then play an investment game in the chosen group structure. Finally, we also explore whether individuals choose the efficient group sizes and invest optimal amounts under different costs of investment. In theory, subjects should vote to form smaller groups when investment becomes more costly. Establishing how players partition themselves endogenously is important, since in the field subjects will *choose* how many groups to form. If players turned out always to vote for a suboptimal number of partnerships, then our laboratory society would never solve the common-property problem even if, as in Schott et al. (2007), it made socially optimal choices when the optimal partnership structure was exogenously mandated.

In our experiment, subjects were divided (exogenously or endogenously) into groups of equal size and played the following investment game. Each subject had to decide how to allocate his or her tokens between two projects. Project A had a return per token invested that was independent of the amount invested. Project B had a higher return per token for the first token invested, but the return decreased linearly with the aggregate investment. Hence,

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[2] To our knowledge, this paper is the first to investigate endogenous output-sharing groups in the setting of a common-pool resource. Whether and how individuals form groups is known to be an important issue in public goods environments (Page, Putterman and Unel 2005; Ahn, Isaac and Salmon 2008, 2009; Charness and Yang 2008; Brekke, Hauge, Lind and Nyborg 2009).

a person's return per token invested in Project B was adversely affected if others invested more in the same project—the essence of the common-property problem. Every member of a given partnership received an equal share of his or her group's return from Project B regardless of his or her own investment in that project. Because investing an additional token in Project B meant that the subject could not use that token to earn the constant return available from Project A, each subject bore his or her own opportunity cost of additional investment in Project B. Our experimental design varies both this opportunity cost and the size of the partnerships. Since partnerships with a single member (solo partnerships) were included, one of our treatments is the standard commons case where there is no output sharing among individuals.

In our experiments, individuals grouped into solo partnerships did overinvest in Project B, to their collective detriment. But as the group size increased, subjects invested smaller amounts in Project B and, as a result, obtained higher payoffs as theory predicts. When given the opportunity to *choose* the size of their partnerships, most of the subjects voted for the group size that maximized the joint payoff (which is socially optimal), and subjects cut the waste associated with the common-property problem on average by at least two-thirds in three of the cost treatments and by one-half in the remaining cost treatment. When we varied the opportunity cost of investing in Project B (the return from Project A), subjects tended to vote for the group size that became socially optimal given the new circumstance.

However, systematic departures from the theory were also noted. When the exogenous number of groups is predicted to yield socially optimal aggregate investment, there is no statistically significant departure from the theoretical prediction. However, when the number of groups is predicted to yield aggregate investment that is either below or above the social optimum, there are statistically significant departures from the theoretical predictions, and *without exception* they are in the direction of the socially optimal investment. Hence, as elsewhere in the literature, we find that laboratory behavior is more "cooperative" and "other-regarding" than a theory based on self-interested behavior would predict (i.e., Ostrom et. al. 1992; Ostrom et al. 1994; Ledyard 1995; Camerer 2003; Falk, Fehr and Fischbacher 2005).

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 discusses directions for future research and concludes the paper.

2 Experimental Design and Procedures

We conducted 25 sessions, each with a different set of 6 participants. Most participants were undergraduates at University of Michigan. 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.

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.

The return per token invested in Project B, $A(X)$, was a decreasing linear function of the aggregate investment in Project B; i.e., Project B represented the common-pool resource. For each token invested in Project B, the return from Project B was given by

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

An individual's earnings from Project B (E_{ik}) depended on the participant's group investment in Project B and the group size (m):

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

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.[3]

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. As Table 1 reflects, 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

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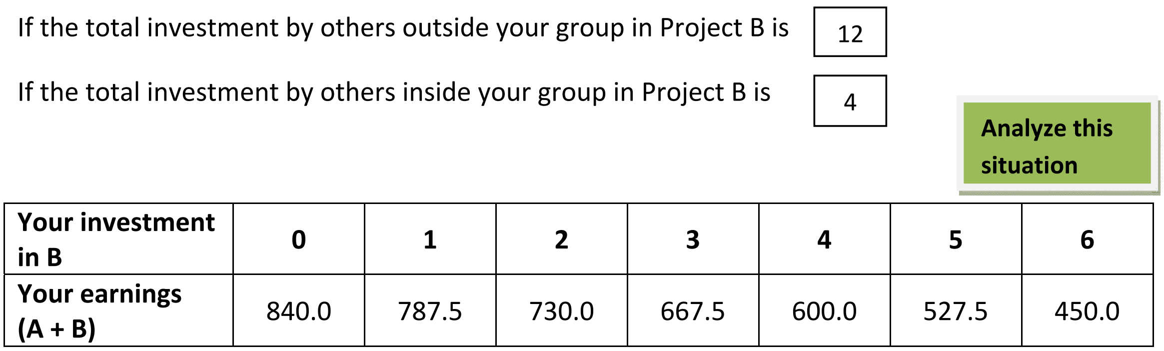
[3] In cases of a tied vote, the winner was chosen at random.

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.

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

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 help subjects to make a decision, subjects were also 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). Each individual chooses his or her investment level to maximize his or her own payoff given the investments of other individuals. Proposition 1 summarizes the Nash equilibrium investments.

Proposition 1. For a given opportunity cost (c) and equal-size groups of size m, mean investment in Project B is $\bar{x} = \frac{200-cm}{30+5m}$.[4]

On the other hand, socially optimal investment of the 36 tokens, X^*, maximizes revenue from the two projects: $XA(X) + (36 - X)c$. Proposition 2 provides the socially efficient investment.

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

When group size is one (no output sharing), it is easy to see that in equilibrium there is overinvestment in Project B relative to the socially optimal level. However, as the group size increases, theoretically predicted investment level decreases. In fact, for each cost parameter, it is possible to find a group size that approximately generates the socially optimal investment in Project B. The optimal group size m^*, *partnership solution*, is the group size that (approximately) equates $\bar{x}$ to x^*. In general, we expect partnership solution to increase efficiency close to the socially optimal levels, if not to the same level.

In Table 2, we show the predicted levels of mean investment in Project B corresponding to each group size for each level of the opportunity cost of investing in Project B.[5] For any

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[4] Total investment is uniquely determined in the equilibrium. However, there are multiple equilibria. Therefore, we focus on the mean investment level. See Heintzelman et al. (2009) for more details.

[5] In this experiment, subjects faced a discrete action space. Though the theoretical predic-

opportunity cost (c), Nash equilibrium investment in Project B decreases with the size of each group. Moreover, investment in that project decreases with the opportunity cost for any group size. Socially optimal outcomes (partnership solutions for each cost parameter) are shown in bold.

Table 2: Theoretically Predicted Levels of Investment

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

We test the following hypotheses:

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.

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tions 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. Furthermore, because the total payoff function is quadratic in investment, first-order changes in the investment in Project B induce only second-order changes in payoffs. In other words, players receive a payoff in the discrete case that is very close to that of the continuous case. Since both the actions and the payoffs of the two cases are very similar, the game played in our experiment very accurately captures the continuous-action game.

Hypothesis 3. In Part V, subjects should vote to establish groups of the socially efficient size.[6]

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

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). 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.[7] Consistent with the theoretical predictions, contributions decrease with the group size for any cost level.

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

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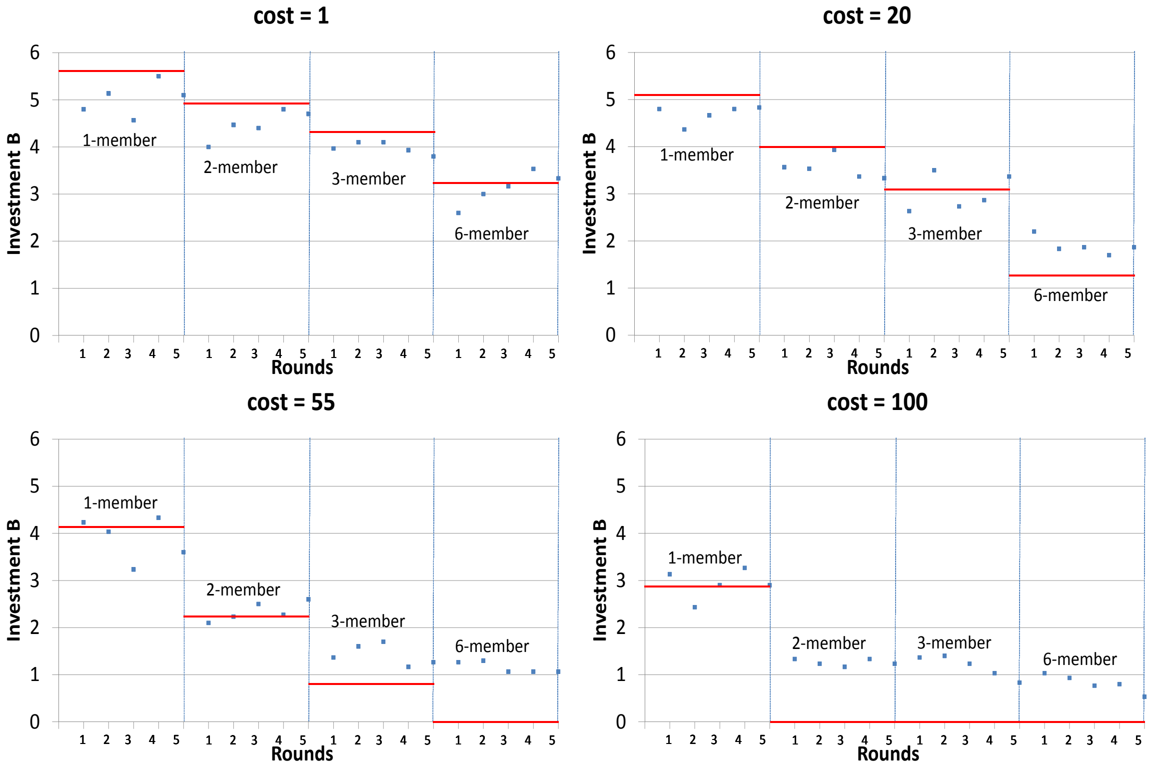
[6] As is well known, this voting game has multiple Nash equilibria. For example, a unanimous vote for any alternative is a Nash equilibrium, since no voter is "pivotal." To avoid such problems, we piloted a second voting mechanism which has a unique Nash equilibrium: after each subject had voted for his or her preferred outcome, one of the six subjects was chosen to be "dictator," and his or her vote determined the partnership structure. Since every subject had a positive probability of being chosen dictator, each subject should have been motivated to vote for his or her most preferred alternative. We were unable to distinguish behavior under the two voting schemes and therefore used the more familiar nondictatorial scheme for this paper.

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

Figure 2: Mean Investment



investment.

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 are greater than 0.1). For nonoptimal group sizes, point predictions do not hold in general (p-values are generally less than 0.05).[8] However, all deviations are toward the socially optimal level.

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[8] 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.

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								

Result 1: *Theoretical predictions hold 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.[9]

For cost levels $c = \{1, 20, 55\}$, we test whether the Partnership Solution improves the

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[9] 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).

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								

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 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).[10]

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[10] Data are clustered by 20 sessions.

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 ** $p < 0.01$, * $p < 0.05$				

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.[11] In addition, we see that the order of treatments and experience do not affect investment decisions.[12] In summary, one cannot reject hypotheses 1 and 2. Our results are robust to different estimation methods.[13]

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 and group size. 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 $c = 20$.

For each cost parameter, we test whether one can reject the null hypothesis that the

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[11] 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). We find the same result for cost parameters as well.

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

[13] 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.

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

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 = 0.00). For $c = 100$, one cannot reject that the proportion of votes is 25% for each group size (p-value = 0.10). More important, 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 = 0.00). 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. In addition, we conduct a multinomial logit regression analysis to test whether votes are affected by cost, previous earnings and experience.[14] 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.[15] Regressors are jointly significant at the 0.05 level (Wald chi-square =

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[14] 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 did not change.

[15] The earnings in each part are calculated by adding up each payoff from the 5 corre-

74.93, p-value = 0.00). In addition, we find that both cost and bestgroup significantly affect votes (Wald tests, p-value = 0.03 and p-value = 0.00 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.[16] 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).

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

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sponding rounds.

[16] 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.

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

c	Group size	Frequency (out of 25)	Investment		Payoff	
c = 1			Predicted	Observed	Predicted	Observed
	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)
c = 20			Predicted	Observed	Predicted	Observed
	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	–
c = 55			Predicted	Observed	Predicted	Observed
	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)
c = 100			Predicted	Observed	Predicted	Observed
	1	7	2.86	2.67 (1.51)	641	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)

on the chosen group size.[17] 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).[18] Moreover, qualitative results are similar to the case when groups are exogenously imposed: investment decreases with the group size (p-value = 0.00) and cost (p-value = 0.00). 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.

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

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[17] 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.

[18] 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.

5 Discussion and Conclusions

In this paper, we find that output sharing attenuates the common-property problem independent of the opportunity cost of investing in the common-pool resource. Consistent with theoretical predictions, we find a negative relationship between the aggregate investment levels (the counterpart to fishing effort) and group size. For a given group size, we show that aggregate investment in a common-pool resource decreases as the opportunity cost of investing in it increases. More importantly, we show that socially optimal group sizes are the most common outcome of the endogenous group formation stage under most of the cost parameters.

Regarding the point predictions, we find that partnership solution (exogenous implementation of socially optimal group size) generates theoretically predicted levels of investment. However, in general, theory does not predict the magnitudes very well for the nonoptimal group sizes. For any deviations from equilibrium predictions, we see that investments shift toward the efficient outcome.[19] One explanation for this is that individuals are altruistic. If individuals care not only for themselves but also for others, then one would expect to see higher levels of efficiency than a theory predicated on the assumption of self-interested behavior would predict (except when the theory predicts socially optimal outcomes). This is highly consistent with our experimental data. Moreover, this type of behavior has been commonly observed in other experimental studies on common-pool resources and public goods (see Ostrom et al. 1994; Ledyard 1995).

Future research should address the stability of the partnership mechanism and its sensitivity to inter subject communication. By stability, we mean migrations of subjects among existing groups or from an existing group to a newly formed group.[20] The effect of inter-

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[19] We focus on the exogenous groups since there are very few data points for statistical testing for endogenous groups at the nonoptimal group sizes.

[20] After the voting stage but before the investment stage, a migration stage could be

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 interplay between communication and endogeneity to future research.

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inserted. Subjects could be permitted to migrate simultaneously from the partnership chosen for them in 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.

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