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Shut Up and Fish: The Role of Communication when Output-Sharing is used to Manage a Common Pool Resource

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Abstract

Schott et al. (2007) have shown that the "tragedy of the commons" can be overcome when individuals share their output equally in groups of optimal size and there is no communication. The assignment to groups as either strangers or partners does not significantly affect this outcome. In this paper we investigate whether communication changes these results. Communication reduces shirking, increases aggregate effort and reduces aggregate rents, but only when communication and output-sharing groups are linked. The effect is stronger for fixed-membership output-sharing groups (the partner treatment) than for output-sharing groups with randomly reassigned members (the stranger treatment). Performance is not distinguishable from the no-communication treatments when communication is present but groups are sharing output within groups other than the groups within which they communicate. Communication also tends to enhance the negative effect of the partnered group assignment on the equality of individual payoffs.

Key words: Common pool resources, communication, coordination, cooperation, free-riding, behaviour in teams, partners and strangers, experiments

JEL classification codes: Q20, C91, D70, C92, C71, C72

1. INTRODUCTION

The efficient supply of effort is a concern for many different economic areas. Groups, teams or businesses are often in conflict with each other over the division of payoffs from a common market, tournament or common pool resource (CPR), and need to overcome free-riding on the provision of effort within their group. Examples include the harvesting of migratory fish stocks by several inshore communities, the extraction of groundwater from aquifers by different municipalities, states or countries, research contests or getting a department representative to serve on a university committee. Such environments are particularly interesting because of the interplay of conflicting incentives within and between groups. The conflict between groups can be described by a tournament or a CPR game, while the within group conflict is typical of a public goods game. Several studies have explored the cooperative and non-cooperative outcomes in these games, but only a very limited number of studies have explored what causes cooperation and coordination within and between groups.

Previous experimental studies have shown that communication in the form of non-binding cheap talk improves cooperation in common-pool resource and public good games (Ostrom et al., 1994; Ledyard, 1995) and can overcome the "tragedy of the commons" or free-riding behavior in the provision of public goods. This implies that the decentralized governance of CPRs and public goods is possible as long as members of a single group are able to communicate with each other on a regular basis, and are not in conflict with other groups appropriating from the same CPR.

A few studies have examined the effect of communication in inter-group public good games. Three studies that involve a step-level public good game played within two groups, with the threshold determined by the contribution level of the opponent group (Rapoport and Bornstein, 1989; Schram and Sonnemans, 1996; Zhang 2009) report a significant increase in group contributions when within-group communication is allowed. Sutter and Strassmaier (2008) evaluate intergroup and between-group conflict with and without communication in a tournament game that involves two teams that compete for a fixed prize which the winning team members share equally. They find that free-riding dominates when teams either cannot communicate or can only communicate with members from other teams. Communication within teams, on the other hand, enables teams to coordinate actions and overcome the free-rider problem. The latter is in the interest of principals or employers but not in the collective interest of team members because they supply excessive levels of effort in order to win the prize. In the tournament design there is no connection between the output teams produce and the effort they supply. A CPR environment establishes a direct link between individual and group effort and total output because teams receive a share of output depending on their supply of effort relative to all other teams and the total effort supplied by all individuals. This furthermore enables us to derive the socially optimal allocation of effort and to evaluate deviations from the optimal aggregate effort level.

Intergroup conflict in CPRs without communication has been examined by Schott et al. (2007) and Heintzelman et al. (2009) for equal output-sharing partnerships in a CPR environment. Output sharing introduces a free riding incentive which potentially has the power to offset CPR over-extraction. Schott et al. (2007) examine strategic interactions both within and between groups in a laboratory setting where output sharing in partnerships is allowed. Partnership sizes were varied between single resource users (no output sharing), a socially optimal partnership size and a larger than optimal partnership size. They find that sharing output in partnerships significantly reduces appropriations from the common pool because the resource user's tendency to over extract from the resource (between-group conflict) is substantially offset by his or her tendency to free-ride on the efforts of other group members (within-group conflict). They also find that when the optimal group size is established, the groups allocate the optimal amount of effort in appropriating from the common pool. The latter is shown to be a socially optimal group Nash equilibrium and is independent of random (stranger) or fixed (partner) assignment to groups. Heintzelman et al. (2009) study the endogenous formation and stability of output-sharing groups and determine the conditions under which output sharing in optimal partnerships becomes a subgame perfect Nash equilibrium in a two-stage game.

Communication among members of a group is an important factor influencing the success of an output-sharing plan. Laboratory results for public goods environments with communication indicate that under-contribution, which characterizes environments with no communication, disappears with communication (Isaac and Walker, 1988; Ledyard, 1995; Chan et al., 1999; Kinukawa et al., 2002). For the CPR environment, these results suggest that communication among group members may lead to coordination that offsets the free riding incentives provided by output sharing, thereby causing an inefficient increase in harvesting effort. The impact of communication on individual effort supply when communication is confined to subgroups of players, therefore, needs to be examined in more detail. Furthermore it is important to investigate how the effectiveness of output sharing in optimal sized partnerships is affected when there are different ways groups can communicate and how institutional features such as the anonymity and rotation of partnerships might have an impact on the type of messages used by groups and, therefore, on the impact of communication on individual effort supply.

The purpose of this paper is to investigate the effect of communication on effort supply in different output-sharing partnership environments and to investigate the relationship between the provision of effort and the type and volume of messages. We design a CPR game with equal output-sharing in partnerships, which allows us to analyze within and between group conflict and to evaluate deviations from the socially efficient outcome. We derive hypotheses based on theoretical insights and empirical evidence from past experimental studies for a variety of communication-sharing environments that capture realistic depictions of possible output-sharing practices and communication patterns within and between partnerships. We then evaluate individual and group behaviour in a controlled laboratory experiment with online communication in chat rooms. We contrast our results to no-communication treatments with partners and strangers, and other related empirical results in the literature.[1]

The first environment we examine reflects the case of a number of communities, businesses or social groups that communicate among themselves, share output equally with members from their community or group, but compete for the yield from the CPR with other communities or groups. This setting takes the "partners" treatment presented in Schott et al. (2007) and allows output-sharing partners to communicate within their group every period. The treatment is comparable to Sutter's and Strassmair's (2008) communication within teams treatment in a tournament setting. A second scenario randomly assigns subjects to groups every period (a strangers treatment). Group members then share output equally and communicate with each other, but are randomly allocated to new groups (within which members can then

[1] In an expanded version of this project we will analyze the frequency and content of messages in the different communication treatments and try to explain how message content and frequency are related to differences in behaviour.

communicate) at the start of each round. This scenario is relevant for centralized allocation to randomized output-sharing groups and would be applicable if the central manger announced the identities of randomized group membership before each period of extraction began. It also allows us to evaluate intra-group communication in a one-shot stranger setting, i.e. to further delineate the effects of partner assignment and communication within groups on effort levels. The high effort levels observed by Sutter and Strassmair (2008), for example are the cause of the communication and partner treatment and our design explores if the strong cooperation within groups subsists if groups are reassembled each period. Our third, and final, scenario is one in which groups always communicate with the same group members (as in many communities or business groups) but share output randomly with others not necessarily from their community or team. This scenario, in which communication groups and output-sharing groups are not linked, is a potentially important middle ground if linked output-sharing groups are able to avoid free-riding on each other thereby circumventing the efficiency enhancing attributes of output-sharing in partnerships without communication

2. EXPERIMENTAL DESIGN

The common-pool resource environment implemented in this experiment requires participants to allocate a fixed amount of effort, e, between an activity which will provide a certain return per unit of effort, r, and an activity which will provide a return that depends upon the effort expended by all of the participants who are trying to obtain output from the common-pool resource. The total output and return (price is normalized to one) from the common-pool resource is given by:

$$Y = 32.5\,X - 0.09375\,X^2 \qquad (1)$$

where Y is total output and X is the sum of the effort expended by all attempting to appropriate from the common-pool resource. We implement a design which includes four factors: production group assignment, communication, communication group assignment and linkage. The last three are relevant only when communication is present. We test three communication treatments: a fixed-fixed-linked (FFL) specification in which appropriators are assigned to output-sharing groups for the entire session and group members are permitted to communicate prior to each decision round, a random-random-linked specification (RRL) in which appropriators are randomly assigned to output-sharing groups prior to each decision round in a session and the group members are permitted to communicate prior to their appropriation decisions and a fixed-random-not-linked (FRNL) specification in which communication groups remain fixed but output sharing groups are scrambled every period and no longer linked to the communication group. We compare these with no-communication treatments in which output-sharing groups are either fixed (F) or randomly assigned each round (R). We analyse harvesting effort, relative rents and dispersion of payoffs by treatment. We also code and analyse the content of the chat messages.

There are 12 participants in each session who are assigned to three output-sharing groups of 4 participants each. This is the optimal group size for a common-pool resource environment which uses output sharing as a management instrument given the parameterization in Schott et al. (2007). Table 1 summarizes the five treatments in this experiment.

Communication is introduced by way of a chat window that appears on the computer screens of the participants.[2] Prior to the first decision round, individuals are given four minutes to send messages to other members in their communication group. No private messages are allowed. After the four-minute communication period, individuals make private and anonymous decisions about the number of units of effort they will allocate to appropriation from the common pool. The remaining units of effort are automatically allocated to the activity that yields a certain payout per unit of effort (i.e. acts as an opportunity cost of effort). Subjects then share the output from the common pool amongst all output-sharing group members and are given a summary providing their earnings for the period. Prior to the second and third decision rounds, individuals are given three minutes to communicate. Prior to the fourth round this is set at two minutes and from the fifth through the fifteenth rounds, communication is limited to one minute.

[2] Bochet et al. (2006, 1) "compare three forms of communication in public goods laboratory experiments [and] find, that face-to-face communication has very strong effects, but surprisingly that verbal communication through a chat room preserving anonymity and excluding facial expression, etc. was almost as efficient. Numerical communication, via computer terminals, had no net effect on contributions or efficiency."

Communication is non-binding. Individuals are not required to adhere to any agreement they may have reached during the communication period by way of the chat window.[3]

2.1. Treatments R and F

In the conventional common-pool resource environment, each participant receives a share of the total output appropriated from the common-pool that is in proportion to the participant's share of effort expended, x_i /X , where x_i is the output of individual i. In this treatment, the participant's profit function depends upon individual effort, x_i , the effort by all four members of the individual's group, X_g , and the effort by all individuals using the common-pool resource. Output is distributed to output sharing groups in proportion to their group effort and this output is distributed equally to all group members. The individual profit function is given as

$$\pi_i = r(e - x_i) + (1/4)(X_g/X)Y \qquad (2)$$

If r = 3.25 and e = 28, substituting equation (1) into (2) , differentiating π_i with respect to x_i and setting this equal to zero yields

$$[(32.5 - 13)/0.09375] = X + X_g \qquad (3)$$

There is an equation like (3) for each member of each group. When the groups have more than one member, the equations for all of the members in any particular group are identical. Using m as a group identifier, for this case we have three unique equations of the form $[(32.5 - 13)/0.09375] = X + {}^{m}X_g$.

In the case of three four-person groups, there are three equations with three unknowns, ${}^{1}X_g$, ${}^{2}X_g$, and ${}^{3}X_g$. Solving these three equations for the three values of ${}^{m}X_g$ we find the group Nash equilibrium values ${}^{m}X_g = [(32.5- 13)/0.09375]/[4] = 52$.[4]

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3 Groups used up to 234 seconds, 178 seconds, 177 seconds and 118 seconds in the first four periods and less than 60 seconds in the following periods. Thus there was no evidence that decisions were forced because of time pressure in our experiment.

4 It is important to note that there is not a unique equilibrium quantity for the individual. The equilibrium condition requires that the sum of the contributions of the individuals in a group equal a unique value. There is a

Treatments R and F are differentiated by the manner by which participants are assigned to output-sharing groups. Although theory offers no prediction on the effect of group assignment, Schott et al. (2007) report that the dispersion of cumulative earnings for the individual participants is significantly reduced in random group assignment compared to fixed group assignment. One possible explanation they provide is that individual players are more likely to manipulate others' future choices in a fixed group assignment because they can best respond to other players accounting for the efforts from previous periods. When within-group communication is introduced, one might expect the relationship between communication groups and output-sharing groups will be important. Because the theory is static, the solutions are for *one-shot* games.

2.2. Treatments RRL, FFL and FRNL

The parameters underlying treatments RRL, FFL and FRNL are identical to those for treatments R and F with the addition of non-binding communication by way of an electronic chat room among subgroups of the 12 participants in each session prior to the start of each decision round. Communication typically helps individuals in groups to overcome the tendency to shirk when payoffs can be characterized as the return to a public good, but it also helps them to reduce effort exerted in the extraction of the common pool in the absence of output sharing (Ostrom, et al., 1994, Chapters 7, 8; Muller and Vickers, 1996). When output sharing is used as a management instrument in a common-pool resource environment without communication, it succeeds because individuals shirk on others' effort to appropriate on behalf of the group. Introducing communication may break down this shirking behavior as members of the group attempt to collude and compete against other groups to obtain a larger share of the system output.

Profit for the group can be found by aggregating equation (2) across the four members of the group. This is expressed as

$$\pi_g = 3.25(28)4 - 3.25X_g + 32.5X_g - 0.09375X(X_g) \qquad (4)$$

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unique group Nash equilibrium allocation of 52 units of effort to appropriation from the common pool from each group. This is the optimal effort to allocate to appropriation from the common pool (see Schott et al. (2007).

Differentiating π_g with respect to X_g and setting this equal to zero yields $X_g + X = 29.25/0.09375$. Using the methodology described in section 2.1., and indexing the group contribution X_g as ${}^mX_g$ we obtain ${}^mX_g = 312/4 = 78$. This is the unique Nash equilibrium for each group when there are three four-person output-sharing groups who compete against each other for system output. There is no unique individual Nash equilibrium level of effort allocated to appropriation from the common pool. Note that when the output-sharing groups compete against each other as groups, system appropriation is predicted to rise from the optimal level of 156 to 234.

3. EXPECTATIONS REGARDING EFFORT

3.1. Treatments R and F

Given the parameterization of the common-pool resource environment introduced in section 3, the expectation is that with three four-person output-sharing groups each group will supply 52 units of effort for appropriation from the common pool. The system effort will be 156 units. This is the expectation for group and system effort for both treatments R and F.

3.2. Treatments RRL, FFL and FRNL

If communication groups and output-sharing groups are linked (treatment RRL), then it is possible that the effect of output sharing may diminish. This may occur if individual players act collusively and exchange information about the optimal level of effort in the one-shot version of the CPR game for which the group wants to maximize its share of system output. This suggests that within the context of treatment RRL and FFL, group effort will be greater than the optimal level of 52 units and may approach 78 units. However, it may take longer to reach 78 units for treatment RRL than if the output-sharing and linked communication groups had fixed membership throughout the session, such as in treatment FFL, since trust built up in early rounds could lead to quicker coordination in later rounds.

On the other hand, it will be difficult for individuals to coordinate on a specific group strategy when communication groups and output-sharing groups are not linked (treatment FRNL). This difficulty arises because individuals will not know into which output-sharing group their communication group members are placed. However, comparing the FRNL treatment with the F or R treatments, participants may be better able to deduce and agree on achieving the symmetric Nash equilibrium outcome in which everyone allocates the optimal level of 13 units of effort to appropriation to maximize the system output. This achieves the maximum equal payout solution that can be realized. This is not a unique Nash equilibrium allocation for the individuals, but the focus on the symmetric Nash equilibrium is reasonable given that communication groups are not linked to output-sharing groups. Treatment FRNL may be more likely to induce more shirking than the other treatments because participants will have a weaker incentive to focus on group output maximization than on system output maximization. This treatment may also induce a more equal distribution of revenues, which was a characteristic of the outcome of the randomly assigned output-sharing groups without communication studied by Schott et al. (2007).

The following expectations follow from the discussion above:

1) Effort allocated to appropriation from the common pool will not differ between treatments R and F.
2) Effort allocated to appropriation from the common pool will be greater in treatment FFL than in treatment RRL during early periods of a session.
3) Effort allocated to appropriation from the common pool under treatment RRL will tend to converge over time towards that from treatment FFL.
4) Effort allocated to appropriation from the common pool will be less in treatment FRNL than in treatments RRL and FFL.

4. RESULTS

A total of 240 subjects in 60 groups of 4 participated in our experiment. There were four sessions in each of the 5 treatments. In each session, 3 groups of 4 subjects participated in 15 decision rounds after 3 practice rounds. Laboratory currency was converted at the exchange rate of 200 Lab dollars for 1 Canadian dollar 1. On average, subjects earned $25 each (the standard deviation was $2 and earnings ranged from $17.70 to $30.30 including a $5 show-up fee). Sessions were completed within 60 minutes in without communication and within 90 minutes with communication.

Table 2 summarizes the mean system effort allocated to appropriation from the common pool and mean individual session payoff in each treatment. A Kruskal-Wallis test indicates that there is a statistically significant difference among the 5 treatments. (*p*-value = 0.0073 for mean system effort, *p*-value = 0.0034 for mean individual session payoff).[5]

4.1. Aggregate effort

For treatments F and R, the socially optimal Nash equilibrium with players maximizing individual payoffs predicts the mean system effort of 156 units and mean individual session payoff of L$4217. The actual mean system efforts and mean individual session payoffs in both treatments are not significantly different from the predictions (Stata's signtest, two-sided, $n = 4$, *p*-value = 0.625 for mean system effort in both treatments, *p*-value = 0.125 for individual mean session payoffs in both treatments). There is also no significant difference between treatments F and R (Mann-Whitney U test, two-sided, *p*-value = 1.000, $n = m = 4$).

In short, when there is no communication, the mean system appropriation effort and relative rents realized from the common pool are consistent with the equilibrium prediction with individual optimization. Group assignment (fixed versus random) makes no difference. These are identical to the results documented in Schott et al. (2007).[6]

When pre-play non-binding communication is allowed, system effort allocated to appropriation differs significantly from the median of the no-communication treatments (Mann-Whitney U test, *p*-value = 0.0026, $n = 8$, $m = 12$).[7] There is a significant increase in aggregate effort in treatment RRL relative to treatment R (Mann-Whitney U test, *p*-value = 0.0433, $n = m = 4$) and an even larger significant increase in treatment FFL relative to treatment F (Mann-

[5] All non-parametric tests reported in this paper take each session as an independent observation. Test results from an OLS regression using robust standard errors are consistent with all non-parametric tests reported. The regression is of the form syseffort = a + bR + cFRNL + dRRL + eFFL, where the dependent variable is mean system effort per session, R, FRNL, RRL, FFL are treatment dummies, and "a" captures the value of the mean system effort in the F treatment.

[6] We have added an additional repetition of F and R for this paper which confirms the robustness of Schott et al. (2007).

[7] The Kruskal-Wallis test indicates that there is a statistically significant difference among 5 treatments with 4 observations in each treatment, *p*-value = 0.0073.

Whitney U test, p-value = 0.0209, $n = m = 4$). The null hypothesis that the mean system effort in FFL is equal to the predicted value of 234 units cannot be rejected (Stata's signtest, one-sided, p-value = 0.6250, $n = 4$). However, the null hypothesis that the mean system effort in RRL is equal to the predicted value of 234 can be rejected in favor of the alternative that it is less than 234 (Stata's signtest, one-sided, p-value = 0.0625). While the mean system effort in FFL is not different than 234 units, the mean system effort in RRL falls between the predicted value of 156 units with individual optimization (which is achieved in R) and the predicted value of 234 units with group optimization.

Thus our expectation that communication leads individuals to reduce shirking in order to increase group payoffs can be supported by the data. This suggests that communication among group members offsets the free-riding incentives provided by output sharing and leads to an increase in appropriation effort. Moreover, the offset effect is much larger when appropriators are communicating and sharing output with the same group of participants each decision round than with a different group each decision round (comparing FFL with RRL, Mann-Whitney U test, p-value = 0.0209, $n = m = 4$). Intuitively, it is more difficult for appropriators to enter into tacit or explicit agreement regarding appropriation when they are randomly assigned to groups in each decision round. It is even more difficult for appropriators to coordinate effort when they are communicating with the same group across all rounds of a session but sharing output with a different group each round (treatment FRNL). Groups in the FRNL treatment thus performed as well as the no communication treatments, with effort not significantly different from the predicted individual-optimization level of 156 units (Stata's signtest, one-sided, p-value = 0.6250).[8]

Result 1. When subjects are communicating with and sharing output with the same people each round, there is a significant increase in mean system effort in random output-sharing groups (treatment RRL vs. R) and an even larger increase in fixed output-sharing groups (treatment FFL vs. F), where group effort is at the predicted group-optimization level. Compared to random linked group assignment (treatment RRL), fixed linked group assignment (treatment FFL) leads to better coordination and thus significantly more appropriation effort.

8 Appropriation effort in treatment FRNL is not significantly different from treatment R (Mann Whitney U test, p-value = 0.3865, $n = m = 4$) or treatment F (Mann Whitney U test, p-value = 0.1489, $n = m = 4$).

Result 2. Group assignment has a significant impact on appropriation only when output-sharing and communication are linked. No significant difference is observed when communication groups and output-sharing groups are not linked, and the mean system effort is at the predicted individual-optimization level (treatment FRNL vs. R).

Figure 1 reports the mean system effort across periods in each treatment. After the first decision round, effort in treatment FFL is higher than all the other treatments across rounds. This series shows a bit of a cycle that ends near to the predicted effort of 234 units. The RRL series falls between the FFL and FRNL treatments. The difference between treatment RRL and treatment FRNL is, however, not significant (Mann-Whitney U test, p-value = 0.1489, $n = m = 4$). Ignoring the first decision round where subjects were getting acquainted with the rules of the game and the last decision round with potential end-game effects, none of the series display a convergence pattern. Thus the role of communication in improving the understanding of the game does not appear to be crucial in any of the treatments other than FFL

Result 3. When output-sharing group membership changes after each decision round, whether communication group is linked (treatment RRL) or not linked to the output-sharing group (treatment FRNL) makes no significant difference to system effort.

Result 4. None of the treatments indicate a convergence pattern.

4.2. Payoffs to participants in the CPR

The impact of output sharing on the returns to the participants is also important to evaluate as adverse equity considerations or reduced incomes are likely to hinder the approval of a regulatory mechanism even if it is economically efficient.

With output sharing in groups of four, the average individual session payoff reaches a maximum at the socially efficient level (52 tokens per group), which equals 4217 lab dollars in our experiment.

Table 3 reports the mean and coefficients of variation of payoffs (CoV) of individual session payoffs. An OLS regression with robust standard errors indicates significant differences between the mean CoV of payoffs across treatments. The smallest CoV of payoffs is observed in treatment FRNL while the biggest is in FFL (Table 4).[9] Pairwise comparisons of the mean CoV between treatments indicate significant differences between all paired treatments except treatments RRL and R. With linked communication groups the distribution of session payoffs for fixed output-sharing groups is less equitable than that of the random output-sharing groups, just as in the no-communication treatments. In addition, the payoffs for participants in the former treatments are less than those in the latter. However, when communication groups are fixed and output-sharing groups are randomly matched and no longer linked with communication groups, payoffs are most equitably distributed among the five treatments and payoffs are significantly greater than those realized by participants in the communication treatments utilizing fixed output-sharing groups. This supports the conjecture in Schott et al. (2007) that random output-sharing groups would likely be more desirable than fixed output-sharing groups in an environment involving communication. Figure 2 displays the distributions of individual session payoffs across the five treatments.

Nonparametric tests on mean individual session payoffs, whose distributions are presented in Figure 2, indicate similar results. Taking one observation in each session, there is no significant difference in the mean individual session payoffs between treatments F and R (Mann-Whitney test, $n = m = 4$, p-value = 0.1489). When communication is allowed but communication groups are not linked with output-sharing groups (treatment FRNL), the mean individual session payoffs are neither significantly different from treatment F (Mann-Whitney test, $n = m = 4$, p-value = 0.1489), nor from treatment R (Mann-Whitney test, $n = m = 4$, p-value = 0.5637). When the linkage between communication and output sharing is established (treatments FFL and RRL), the mean individual session payoffs are significantly different from corresponding treatments F and R, as well as treatment FRNL (Mann-Whitney tests, for comparisons of treatments FFL and F, treatments RRL and R, treatments FFL and FRNL and

[9] The mean CoV in treatment FRNL is significantly different from treatment F, R, FFL and RRL(t test, p-value = 0.0002,0.0114, p-value = 0.0002 and 0.0001 respectively). There is significant difference between treatments F and R (t test, p-value = 0.0091) and also significant difference between treatments FFL and RRL (t test, p-value = 0.0000). Treatment FFL is significantly different from treatment F (t test, p-value = 0.0000) while the difference between RRL and R is not significant (t test, p-value = 0.1480). Treatment R is significantly different from treatment FFL (t test, p-value = 0.0000) and treatment F is significantly different from treatment RRL (t test, p-value = 0.0402).

treatments RRL and FRNL report identical results: $n = m = 4$, p-value = 0.0209). The mean cumulative payoffs in FFL are significantly less than in RRL (t-test, $p < 0.01$).

5. DISCUSSION AND CONCLUSIONS

Communication among group members in a setting in which multiple groups compete with one another may not lead to optimal resource allocation. In particular, the success of introducing shirking incentives through output-sharing groups in a common pool resource environment may not be maintained when communication is permitted among group members. We have shown that groups manage to coordinate quite effectively through cheap talk and induce members to increase effort and therefore to avoid free-riding on the effort of others that is so apparent in output-sharing partnerships without communication. While shirking is reduced when output-sharing and communication groups are linked regardless of whether the output-sharing groups are fixed over time or randomly reassigned each production period, breaking the link between output sharing and communication has a remarkable impact on efficiency. If output-sharing groups are reassigned each period but communication groups remain fixed over time, shirking in output-sharing groups is not substantially reduced and effort remains at levels comparable to the no-communication treatments. In addition, the average income earned system-wide is higher and more equitably distributed than when communication groups are linked.

This paper reports on the effects of communication in an environment in which appropriators of a common pool resource share output with members of an exogenously formed group. While the evidence suggests best practices for carrying out an output-sharing policy, it also allows for unique insight into the effects of communication in a multiple group setting in which communication is predicted to decrease welfare while the literature on the effect of communication on the provision of public goods and extraction from common pool resources without between-group conflict focuses on the role of communication increasing overall welfare.

In the environment we have presented, an outside agency establishes output-sharing groups as a means to manage the CPR. What remains to be studied is the role of communication and output sharing in an environment with endogenous CPR management – where control mechanism is designed and implemented by the appropriators from the CPR. Will output sharing emerge as a management mechanism in such a setting? Can the appropriators from a CPR reach an efficient allocation through communication and effort constraints approved by all appropriators? Will there be a role for randomly assigned output-sharing groups in this environment?

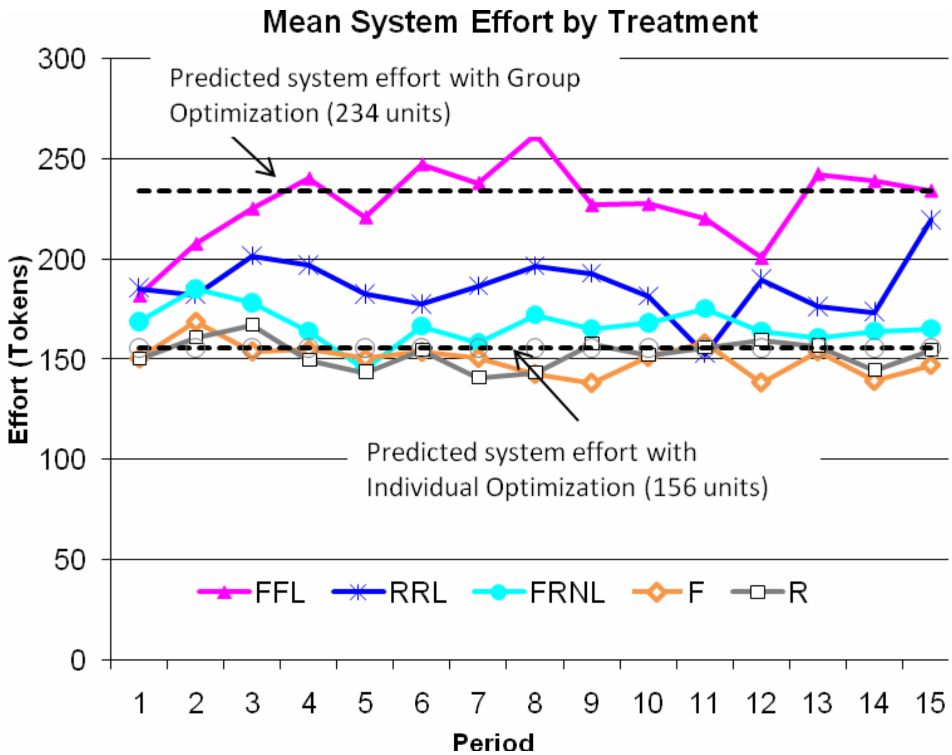

Figure 1. Mean system effort allocated to appropriation from the common pool

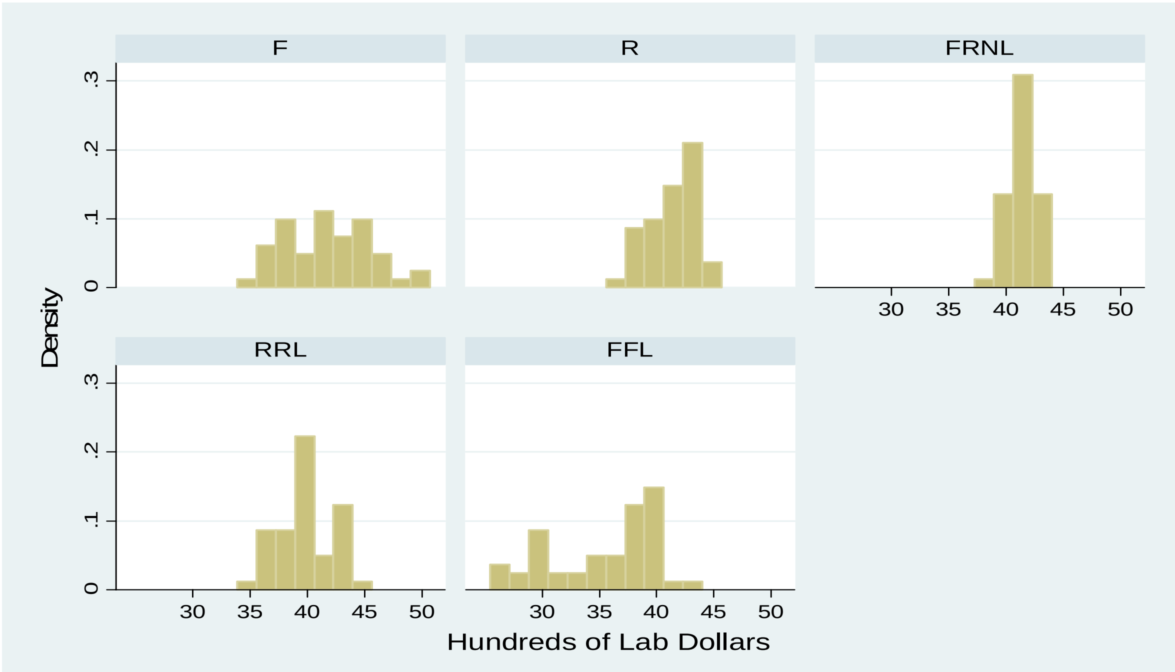

Figure 2. Distribution of individual session payoffs by treatments

Table 1. Experimental Design

Treatment	# of Sessions	Communication	Group Assignment
R	4	No	Random
F	4	No	Fixed
RRL	4	Yes, linked to output-sharing group	Random Communication Group Linked to Random Output Sharing Group
FFL	4	Yes, linked to output-sharing group	Fixed Communication Group Linked to Fixed Output Sharing Group
FRNL	4	Yes, not linked to output-sharing group	Fixed Communication Group not Linked to Random Output Sharing Group

Table 2. Mean system effort and individual payoffs and sample standard deviations by treatment

Treatment	System Effort			Individual Session Payoff in Lab Dollars	
	Mean	Standard Deviation	Prediction	Mean	Standard Deviation
F	150.40	8.16	156	4174	370.24
R	152.77	7.43	156	4147	200.96
FRNL	166.87	9.14	156	4138	124.66
RRL	186.57	14.94	(156,234)	3990	239.01
FFL	227.92	19.91	234	3528	459.50

Table 3. Mean individual cumulative payoffs and coefficients of variation of payoffs per session by treatment

Treatment	F	R	FRNL	RRL	FFL
Mean cumulative payoffs	4174.26	4147.10	4137.98	3989.53	3528.27
	(21.67)	(33.99)	(42.90)	(61.51)	(123.95)
Mean coefficients of variation	0.09	0.05	0.03	0.06	0.13
	(0.03)	(0.01)	(0.01)	(0.01)	(0.02)

Notes: Sample standard deviations are in parentheses; the means and standard deviations are based upon four observations for each treatment.

Table 4. OLS regressions on coefficient of variation

Treatment	Coefficient (robust standard errors)
F	-0.04**
	(0.02)
R	-0.08***
	(0.01)
FRNL	-0.10***
	(0.01)
RRL	-0.07***
	(0.01)
Constant	0.13***
	(0.01)
Observations	20
R-squared	0.854

Notes: Robust standard errors in parentheses; *** $p \leq 0.01$, ** $0.01 < p \leq 0.05$, * $0.05 < p \leq 0.1$

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7. APPENDIX I

1. Equilibrium for CPR Environment when Individuals in Groups Attempt to Maximize Individual Profits when Output Sharing is Used as a Management Instrument

Total output as a function of "effort" of all individuals using the CPR (X):

$Y = 32.5\ X - 0.09375\ X^2$

Individual Profit as a function of individual effort (x), the effort by members of the individual's group (X_g) and the effort by all individuals using the CPR (X):

$\prod = 3.25(28 - x) + (1/n)(X_g/X)Y$

where n is the number of people in the individual's group. If $n = 1$ then $X_g = x$.

Differentiating $\prod$ with respect to x and setting this equal to zero yields

$-3.25 + (1/n)32.5 - (0.09375/n)(X_g + X) = 0$

This reduces to

$[(32.5 - 3.25n)/0.09375] = X + X_g$

There is an equation like this one for each member of each group. When the groups have more than one member, the equations for all of the members in any particular group are identical. This results in three unique equations of the form

$[(32.5 - 3.25n)/0.09375] = X + {}^mX_g$ where m is the group identifier.

In the case of three four-person groups, there would be three equations with three unknowns, ${}^1X_g$, ${}^2X_g$, and ${}^3X_g$. The solution will be

${}^mX_g = [(32.5 - 3.25n)/0.09375]/[(12/n)+1]$

The important result is that there is not a unique equilibrium quantity for the individual. The equilibrium condition requires that the sum of the contributions of the individuals in a group equal a unique value. There is a unique group Nash equilibrium allocation of effort to appropriation from the common pool.

2. Equilibrium for CPR Environment when Individuals in Groups Attempt to Maximize Group Profits when Output Sharing is Used as a Management Instrument

Individual Profit as a function of individual effort (x), the effort by members of the individual's group (X_g) and the effort by all individuals using the CPR (X):

$\prod = 3.25(28 - x) + (1/n)(X_g/X)Y$

Profit for the group is

Individual Profit as a function of individual effort (x), the effort by members of the individual's group (X_g) and the effort by all individuals using the CPR (X):

$\prod_g = 3.25(28)n - 3.25X_g + 32.5X_g - 0.09375X\,X_g$

Differentiating $\prod_g$ with respect to X_g and setting this equal to zero yields

$X_g + X = 29.25/0.09375$

As demonstrated in section 1, $X_g + X$ may be written as ${}^mX_g + (12/n){}^mX_g$. Therefore,

${}^mX_g = 312n/(12 + n)$

The Nash equilibria in the situations described above result in the following values

Members in Group (Number of Groups)	Group Effort with Individual Optimization	System Effort with Individual Optimization	Group Effort with Group Optimization	System Effort with Group Optimization
1 (12)	24	288	24	288
2 (6)	39.6	237.7	44.6	267.4
4 (3)	**52**	**156**	78	234
6 (2)	46.2	92.4	104	208

Note: The allocation of effort that will maximize system profits occurs when the system effort is 156. This will be a Nash equilibrium if the group size is 4 and each group allocates 52 units of effort to appropriating from the common pool. The distribution of effort among group members is not unique.

8. APPENDIX II

INSTRUCTIONS (Treatment FRNL)

Introduction

You are about to participate in a project about economic decision-making. You will be asked to make decisions about the investment of resources between two activities, which will be referred to as Markets 1 and 2. The amount of money you will earn in today's session will depend on your investment in Market 1 and the sum of your and others' investments in Market 2. Your earnings will be paid to you privately, in cash, at the end of the session. The money for this project is provided by several funding agencies.

The Environment

During this session you and 11 other people will have to make decisions to invest resources in two markets. You will participate in 18 decision rounds, called *periods*. The first 3 periods will be for practice. The last 15 periods will determine your earnings at the end of the session.

At the start of the first round the 12 participants in the session will be divided into 3 groups of 4 people. The distribution of people to groups is random and none of the participants will know who is in his or her group. *After each of the 18 periods is over, we will scramble the membership of all the groups, so that everyone is playing in a new group every period.*[10] Your earnings will depend upon the investment decisions that you make, the investment decisions that the members of your group make, and the investment decisions that the members of the other groups make. Your earnings in each round will be reported to you in Laboratory Dollars (L$). These will be converted to Canadian Dollars (C$) at the end of the session using the relationship 0.0045×L$ = C$.

The Markets

At the beginning of each period you and each of the other participants will be given 28 tokens to invest. These tokens may be distributed in any way you wish between the two markets. Each period you will decide how many tokens to invest in Market 2. Whatever you do not invest in Market 2 will be automatically invested in Market 1.

Each token you invest in Market 1 yields a fixed return of L$3.25. This return per token is independent of the amount you invest or others invest in Market 1. Your return from Market 2 depends on the total investment in this market by all participants in the session.

Although you keep all of your return from Market 1, you and the rest of your group will pool your returns from Market 2 and share them equally. Thus your *payoff* from Market 1 equals your return from Market 1 and your *payoff* from Market 2 equals your share of your groups' returns from Market 2. Your total payoff for the period is the sum of your payoffs in the two markets.

[10] In treatment FFL, the sentence in italic is changed to "After the 3 practice periods are over, we will scramble the membership of all the groups, so that everyone is playing in a new group. Each group of 4 participants remains together throughout the next 15 paid periods". In treatment RRL, the sentence in italic remains the same.

Numerical Example

In today's session there will be 3 groups of 4 participants. Each participant will have an endowment of 28 tokens to distribute between investments in Market 1 and Market 2.

Suppose you invest 11 tokens in Market 2. Assume that each of the other members of your group invests 19 tokens. Assume that each of the other participants (not in your group) invests 17 tokens in Market 2. Here is how your payoffs in Market 1 and Market 2 are calculated:

You invest 11 tokens in Market 2, leaving 17 tokens to be invested in Market 1.

The total investment in Market 2 by the other members of your group is 3×19 = 57 tokens.

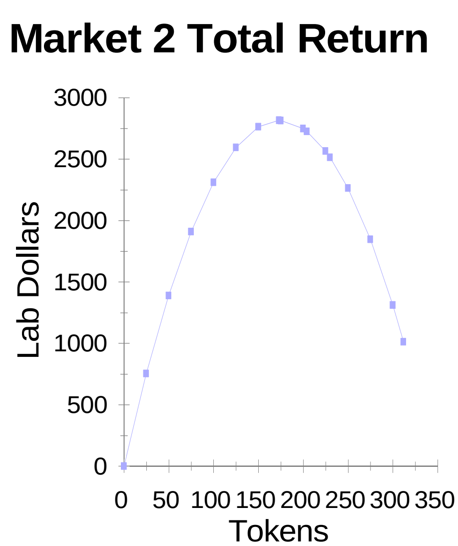
The total investment in Market 2 by the participants not in your group is 8×17 = 136 tokens.

The total investment in Market 2 by all participants is 11 + 57 + 136 = 204 tokens.

The Market 2 Total Return Table shows the total and average return per token for a number of values of total investment in Market 2. If 204 tokens are invested in Market 2 the total return will be L$2728.50. The average return per token is L$13.375.

Market 2 Total Return Table

Tokens	Total Return	Average Return per Token
0	0.00	0.000
25	753.91	30.156
50	1390.63	27.813
75	1910.16	25.469
100	2312.50	23.125
125	2597.66	20.781
150	2765.63	18.438
175	2816.41	16.094
200	2750.00	13.750
204	2728.50	13.375
225	2566.41	11.406
250	2265.63	9.063
275	1847.66	6.719
300	1312.50	4.375
325	660.16	2.031
336	336.00	1.000



Your return from the 11 tokens you invested in Market 2 is L$13.375 ×11 = L$147.125. The total return from the 19 tokens invested by each of the other members of your group is L$13.375 ×19 = L$254.125. Therefore the total return to your group is L$909.50. Since you share this return equally, your total *payoff* from Market 2 is L$909.50/4 = L$227.375.

The constant return in Market 1 is L$3.25 per token. Therefore the return from the 17 tokens you invested in Market 1 is 3.25×17 = L$55.25.

Your total *payoff* from both markets combined is L$55.25 + L$227.38 = L$282.63.

Each of your group partners total payoff, on the other hand, is L$227.38 + 9×L$3.25 = L$256.63.

To simplify these calculations, the computer will show you an abbreviated Payoff Table for Market 2 and a Payoff Wizard which will calculate the exact payoff for any combination of your investment, the average investment by others that are in your group, and the average investment by others that are not in your group. The abbreviated Payoff Table will be similar to the Payoff Table for Market 2 shown below.

Payoff Table for Market 2: Your Payoff Only When There are 3 Groups with 4 Members in Each Group							
Average Investment of Tokens in Market 2 by Members of Your Group		0	6	11	17	22	28
Average Investment of Tokens in Market 2 by All Participants Other Than Those in Your Group	0	0	181.50	312.13	444.13	533.50	616.00
	6	0	154.50	262.63	367.63	434.50	490.00
	11	0	132.00	221.38	303.88	352.00	385.00
	17	0	105.00	171.88	**227.38**	253.00	259.00
	22	0	82.50	130.63	163.63	170.50	154.00
	28	0	55.50	81.13	87.13	71.50	28.00

The payoff based upon the numbers given in the previous section can be easily calculated from this Payoff Table. Since your group invested 11 + 57 = 68 tokens, the average investment by people in your group is 68/4 = 17 tokens. Locate the column headed "17". Since the other participants not in your group each invested 17 on average, locate the row labelled "17". The number at the intersection of these rows and columns (227.38) is your share of your group's return from Market 2. Adding L$55.25 (your payoff from Market 1) to this gives your total payoff of L$282.63.

Practice Periods

To let you learn more about the environment we are going to run **3 practice periods.** The results from these periods will **not** contribute to your final earnings. If you have any questions during these 3 periods, please raise your hand and we will answer them.

After the 3 periods are over, we will scramble members of the groups and begin the 15 periods which contribute to your earnings.

(Monitor starts the session)

Please examine your computer screens. In the upper right hand frame you will find a Payoff Table like the one in your instructions. Locate the cell showing your Market 2 payoff if you invest 11 tokens, the others in your group invest 19 tokens and the people not in your group invest 17 tokens each. To find the cell you must calculate the average investment made by all of the members of your group (11 by you and 19 by each of the other 3 is 68 tokens; divided by 4 equals 17 tokens). Under these hypothetical conditions, your payoff from Market 2 would be L$227.38.

Please click on this cell. Now look at the Wizard at the upper left hand side of the screen. Note that the numbers from the Payoff Table have been entered into the Wizard. Your investment is identified as 17 tokens, the average investment of the others in your group is identified as 17 tokens, and the average investment of others not in your group is identified as 17 tokens. Note the displayed payoff from Market 2 is L$ 227.38 and your displayed Total Payoff is L$263.13.

Now use the spin-edit box to change your investment to 11 tokens and the average investment by others in your group to 19 tokens. Note that your payoff from Market 2 has not changed, but your Total Payoff has increased to L$282.63. This total payoff is identical to the payoff you calculated in the previous example, in which your group average investment was 17, but you invested 11 tokens, while each of the others in your group invested 19 tokens.

You can calculate the payoff for any other combinations of investments by altering the numbers in the spin edit box.

You make your decision by filling in the form at the lower left of your screen. Notice that the spin-edit box on this form shows the last value you entered into the Wizard. You can accept this value or change it any way you please. After you have entered your desired investment decision, push the **Press Here When Done** button.

We are now ready to start the practice sessions. Please make your decisions and submit them.

(after results are shown)

The computer screens are now showing the results of the period. When you are finished examining them, please press **Done**

(after screens change)

You are now ready to start the second practice period. Notice the results from last period are shown on the history page on the right hand side of your screen. Remember that the groups have all been scrambled and you will be in a new group every period. Please make your decisions and submit them as before.

(after results are shown)

The results of the second practice period are now being shown. Please examine them and then proceed to the third practice period.

(after third period begins)

This is the third and final practice period. Please make your decisions and submit them as before. When the results of the third session appear, do not press the **Done** until you have read the remaining instructions.

(after the results appear)

Communication

Prior to the first paid period, you will be able to send messages to other members in your group. Everyone in your group will see the messages you send. To see how, please click now on the messenger tab in the lower portion of your screen. The messenger window will open. Then click on the lower (white) part of the box and type “hello”. Please everyone type “hello” now. Then click the ‘Send’ button, so that others in your group can read your message. If you look at the messenger window you will see how many seconds remain for exchanging messages. The messenger window will be active for four minutes before the first paid period.

After the exchange of messages you will make investment decisions. *Although you will make investment decision in a new group each period, the composition of your communication group is the same across all periods.*[11] More specifically, before making decisions, you will always be able to send messages to the same group as you communicate with in the first paid period.

Prior to the second and third decision periods, this is set at three minutes. Prior to the fourth round this is set at two minutes and from the fifth through the fifteenth rounds, communication is limited to one minute. Now please switch to the main window by clicking on the background.

Although we will record the messages your group sends to each other, only the people in your group will see them. In sending messages, you should follow two basic rules: (1) Be civil to one another and do not use profanities, and (2) Do not identify yourself in any manner. The communication channel is intended to discuss your choices and should be used that way.

Please **do not close any window at any time** because that will cause delays and problems with the software.

Paid Periods

We are now about to begin the paid portion of the session. **We will scramble the membership of all the groups so that your group will consist of a completely new set of 4 people in each of the next 15 periods.**

If you have any questions, please ask them now.

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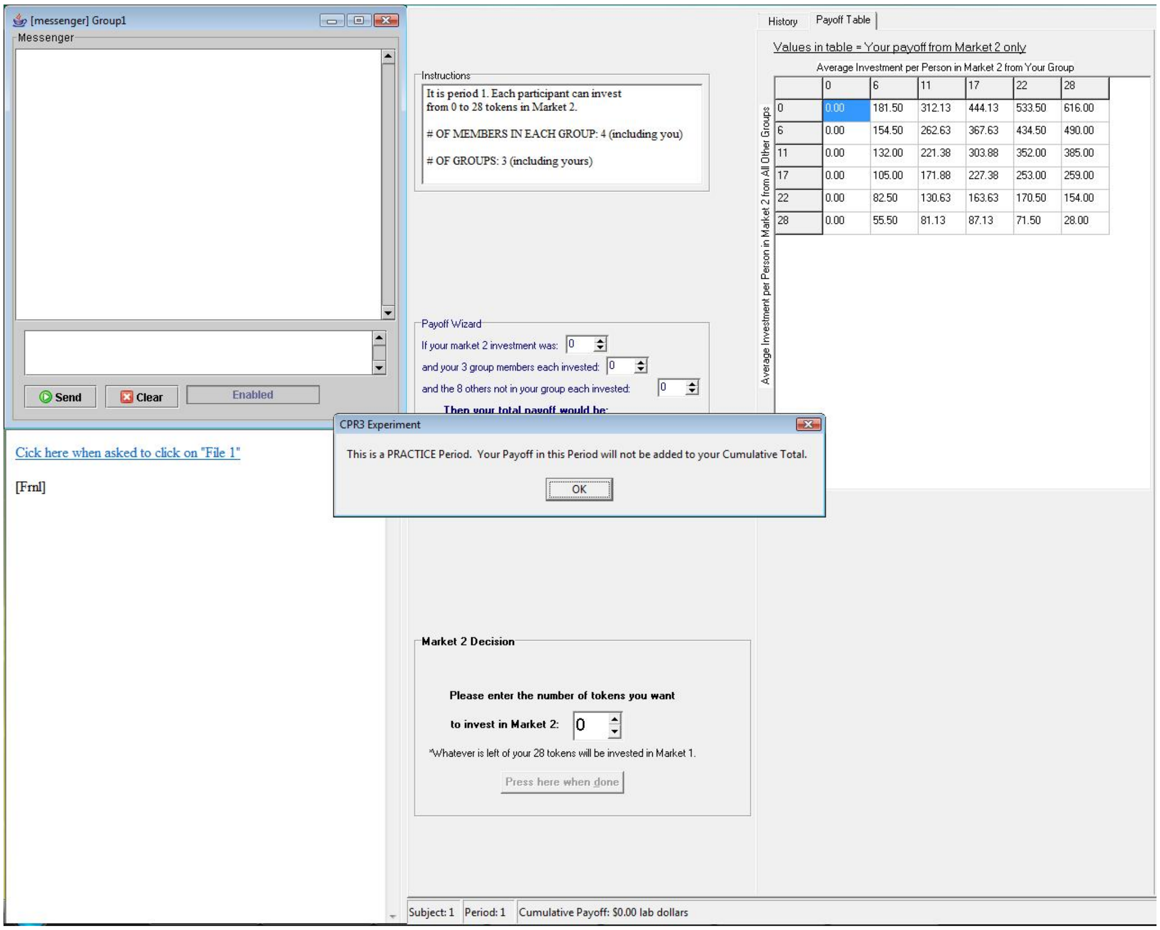
11 In treatments RRL and FFL, the sentence in italic is removed.

Please examine the results of the third practice period and press **Done.** When everyone has done this, the first paid period will begin automatically. Please continue to follow the computer prompts until the end of the session.

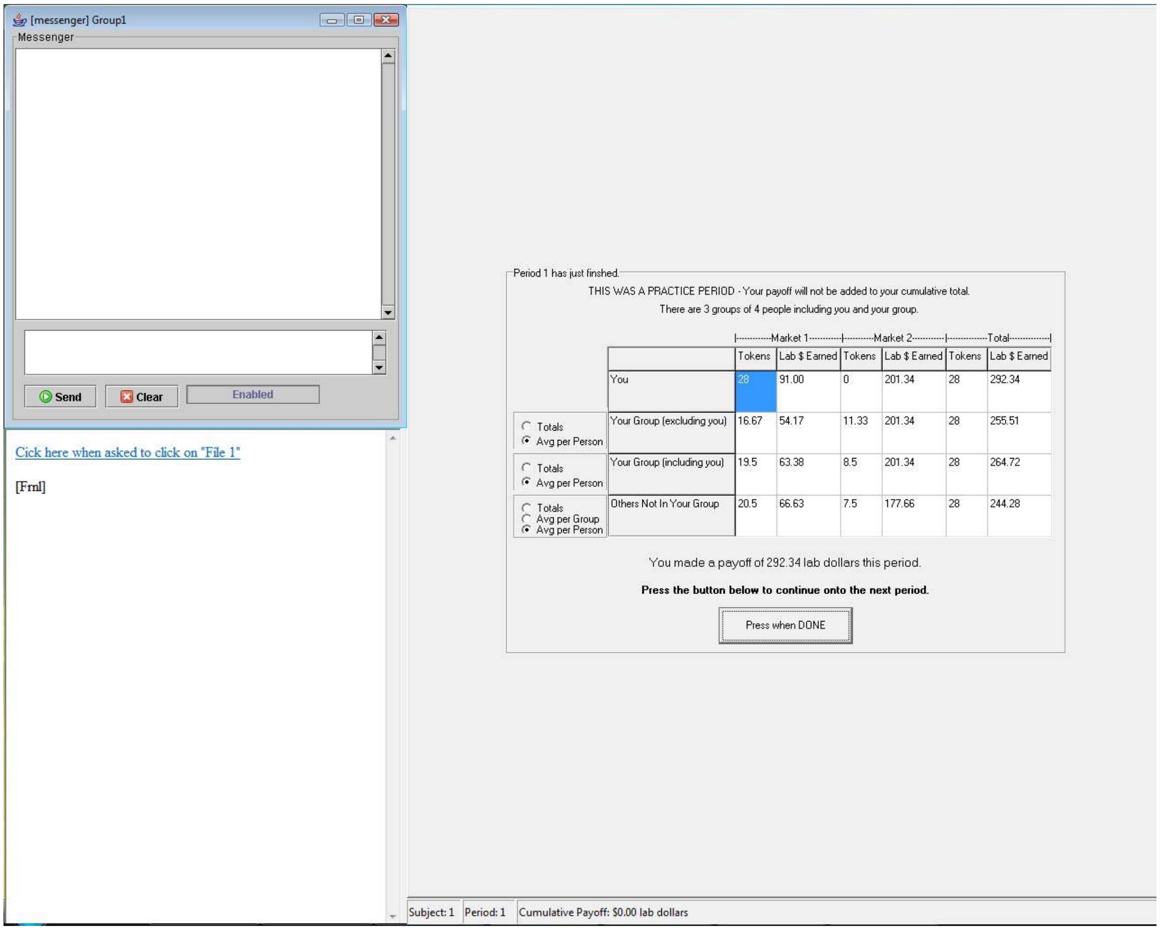
9. APPENDIX III

SCREEN SHOTS



	0	6	11	17	22	28
0	0.00	181.50	312.13	444.13	533.50	616.00
6	0.00	154.50	262.63	367.63	434.50	490.00
11	0.00	132.00	221.38	303.88	352.00	385.00
17	0.00	105.00	171.88	227.38	253.00	259.00
22	0.00	82.50	130.63	163.63	170.50	154.00
28	0.00	55.50	81.13	87.13	71.50	28.00

Decision Screen



Outcome Screen