Effort Provision and Communication in Teams Competing over the Commons

Neil J. Buckley
York University

Stuart Mestelman and R. Andrew Muller
McMaster University

Stephan Schott
Carleton University

Jingjing Zhang
McMaster University and University of Zurich

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Corresponding Author: Neil J. Buckley, 1144 Vari Hall Department of Economics, York University, 4700 Keele St., Toronto, ON, Canada, M3J1P3. Phone: 416-736-2100 x.30106, Fax: 416-736-5987, Email: nbuckley@yorku.ca.

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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. In this paper we investigate the impact of introducing communication groups that may or may not be linked to output sharing groups. Communication reduces shirking, increases aggregate effort and reduces aggregate rents, but only when communication groups and output-sharing groups are linked. The effect is stronger for fixed groups (partners treatment) than for randomly reassigned groups (strangers treatment). Performance is not distinguishable from the no-communication treatments when communication is permitted but subjects share output within groups different from 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. We use detailed content analysis to evaluate the impact of communication messages on behavior across treatments.

Keywords: Common pool resources, communication, coordination, cooperation, free-riding, behavior in teams, partners and strangers, experiments

JEL classification codes: Q20, C92, C72

1. INTRODUCTION

Economic decisions are frequently made by groups of individuals who are competing with other groups of individuals. These may be firms competing with other firms to sell a product in a market or to extract a resource from a common pool, or they may be teams of workers competing with other teams of workers within a firm. Typically, the success of a firm or a team is dependent upon the effort expended by the members of the firm or team. These environments are particularly interesting because of the interplay of conflicting incentives that may exist within and between groups. The conflict between groups may lead to an inefficient allocation of resources. In a tournament all competitors exert effort, but only one may win the tournament and receive the reward. The effort expended by losing competitors goes unrewarded. When extracting resources from a common pool, such as a fishery, competitors impose congestion costs on one another. The effort expended will typically exceed the efficient level of effort necessary to generate the resulting extraction level. When the competing groups are made up of self-interested individuals, further conflicts may arise. For example agents exploiting a common pool resource (CPR) can be placed in a number of output-sharing partnerships as proposed by Schott [18]. Members of each partnership pool their harvest and share it equally. This introduces an incentive for agents to free-ride on their partners by reducing their own work effort. This shirking reduces overall effort and offsets the over-harvesting incentive caused by the between-group conflict.

Schott et al. [19] study the exploitation of CPRs with output-sharing partnerships in a laboratory setting. Partnership sizes are varied among 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 resource-extraction effort. They also find that when the theoretically optimal group size is established, the groups in fact allocate the optimal amount of effort to appropriation. Heintzelman et al. [10] study formally 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.

A complication may arise however if members of the teams can coordinate their actions. For example, coordination amongst team members can eliminate the shirking incentive while leaving the original between-group conflict unabated. Communication among members of a group is likely an important factor influencing coordination. Previous experimental studies with unitary agents (not teams) have shown that communication in the form of non-binding cheap talk improves cooperation in common-pool resource and voluntary public good games and can overcome the "tragedy of the commons" or free-riding behavior in the provision of public goods [5,9,11,12,13,16]. These studies suggest that the decentralized governance of CPRs and public goods is possible as long as agents are able to communicate with each other on a regular basis. They do not address the problem of inter-group conflict, however.

Studies of inter-group conflict versus individual competition have been recently reported for environments with contests for a fixed-value prize [1,2,7] or for the output from a common pool resource [8]. All show that communication within groups affects the outcome of the inter-group game. Abbink et al. [1] study single individuals or groups of four individuals competing with a single individual or with another group of four individuals for a prize of fixed value. They report that inter-group competition results in more rent-seeking than individual competition. When there can be intra-group punishment, even more resources are wasted. Ahn et al. [2] study single individuals or five-person groups competing with either a single individual or with a five-person group for a fixed-value prize. The competitor who bids the most wins the prize. If the five-person group wins, each member receives an equal share of the prize. Ahn et al. (Result 2) found that "individuals show decreased contribution levels when in groups of five rather than when playing as individuals." This result contrasts with Abbink et al. [1] and suggests that in tournaments between teams, rent seeking will fall (but still be greater than the Nash equilibrium prediction). Davis and Reilly [7] study rent-defending groups (with 1, 2 or 5 members) competing against four potential monopolists. The introduction of rent-defending groups increases rent-seeking. However, using the summary data from the last 15 of 30 decision rounds, they find that increasing the size of the defending group from one to five members decreases rent seeking by 20 percent. Overall, rent seeking exceeds the predicted Nash equilibrium levels of rent seeking, but this effect is smaller in larger groups. Gillet et al. [8] study decisions made by groups of appropriators from a common pool. Decisions of groups are made according to a unanimity rule or majority rule. Their environment differs from standard common pool resource environments by introducing a dynamic resource stock. They report that common pool resource extraction determined by a group of appropriators is less myopic, but more competitive, than is extraction by individual appropriators. When decision makers are groups of individuals, there is more rent seeking than when decision makers are individuals.

A few studies have examined the effect of communication in inter-group games. Rapoport and Bornstein [17], Schram and Sonnemans [20] and Zhang [22] study a steplevel public good game played by two groups with the threshold determined by the contribution level of the opponent group. They report a significant increase in group contributions when within-group communication is allowed. Sutter and Strassmair [21] evaluate within-group and between-group conflict with and without communication in a tournament that involves two teams that compete for a fixed prize which the losing team pays and the winning team shares equally. They find that free-riding dominates when teams 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 may be 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.

Coordination induced by communication within output-sharing partnerships is a potential threat to the viability of output-sharing as a management strategy for many CPRs such as fisheries. In a classic fishery dominated by many small fishermen from geographically dispersed villages it would seem natural to form output-sharing teams publicly within each community. Under such circumstances communication within local teams would seem normal, but as we have seen such communication might lead back to the over-harvesting that output-sharing was intended to cure. For this reason the impact of communication on effort and output when communication is confined to subgroups of players needs to be examined in detail. To our knowledge there are no laboratory studies which have addressed these issues in the context of CPRs.

One important aspect of intra-group communication in competition among teams is the composition and longevity of communication and output-sharing groups. These do not need to be identical. For example communication in a fishery might take place within local communities while output-sharing was implemented anonymously over a greater territory, so that team members might be from different communities and might not know each other. A further complication arises if teams are remixed regularly so as to prevent agreements and understandings building up over time. Sufficient anonymity and remixing might eliminate the coordination-enhancing effects of communication.

A second intriguing aspect is the mechanism of communication itself. Exactly how does communication within groups lead to coordination? Investigating such questions requires a protocol for recording and coding messages. One method is to restrict communication to computer-mediated chat rooms and to apply the methodology of content analysis to the transcript in the manner of Zhang [22]. We adopt this method for the present study.

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 that allows us to analyze within and between group conflicts 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 different communication group and output-sharing group arrangements. We then evaluate individual and group behavior 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. Finally we analyze the frequency and content of messages in the different communication treatments and offer insight into how message content and frequency are related to differences in behavior.

We examine three treatments. The first reflects the case of a number of communities, businesses or social groups that communicate and share output equally among themselves, but compete for the yield from the CPR with other communities or groups. This treatment modifies the "partners" treatment presented in Schott et al. [19] by allowing the output-sharing partners to communicate within their group every period. It is comparable to Sutter's and Strassmair's [21] communication within-teams treatment in a tournament setting, but is evaluated here with respect to individual, group and social efficiency criteria. Our second treatment is a "strangers" treatment with communication. Group members communicate with each other and then share output equally, but are randomly allocated to new groups at the start of each round. This treatment reflects centralized allocation to randomized output-sharing groups and would be applicable if the central manager permitted anonymous communication among group members. It allows us to investigate intra-group communication in a one-shot stranger setting and too see whether the strong cooperation within groups and the high effort levels observed by Sutter and Strassmair [21] continue if groups are reassembled each period. Our third and final treatment holds communication groups constant but remixes output-sharing groups each period. This reflects a world in which members of a single community or team regularly communicate with each other, 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. Allowing for fixed group communication alongside anonymous randomized output-sharing group formation might also be a useful mechanism for managers who realize that their teams are over-supplying effort and wish to avoid direct coordination and to reduce excessive competition among competing teams.

2. EXPERIMENTAL DESIGN

Each session involves 12 participants divided into three output-sharing groups of four participants each. Each decision period every participant is required to allocate a fixed endowment of effort, 'e', between a private activity which provides a known return of 'r' per unit of effort and a resource extraction activity which provides a varying return that depends upon the aggregate effort of all 12 participants. In the interest of brevity the term "effort" will henceforth refer only to the effort devoted to resource extraction, unless another interpretation is clearly required by the context.

The total output and return (price is normalized to one) from the common-pool resource is given by

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

where Y is total output appropriated from the CPR and X is the sum of the resource-extraction effort of all participants.[1] Output is distributed to output-sharing groups in

[1] The experiment is conducted with neutral framing. Effort is referred to as "Investment" and the two activities are termed Market One and Market Two.

proportion to their group effort, X_g, and this output is distributed equally to all group members. Thus the individual profit function under output-sharing is

$$\pi_i = \mathrm{r}(\mathrm{e} - x_i) + \frac{1}{4}\frac{X_g}{X}Y \quad (2)$$

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We test five treatments. In two of them, Treatments R and F, no communication among participants is permitted. In Treatment R output-sharing groups are randomized each period. In Treatment F output-sharing groups remain fixed. In the remaining treatments communication is allowed at the beginning of each decision period. In all communication treatments participants are assigned to one of three communication groups of four persons each. The communication group may or may not be the same as the output-sharing group. We refer to these as "linked" and "not linked" treatments, respectively. The output-sharing group may be fixed across periods or randomized at the beginning of each period. Thus we have three communication treatments: a fixed-fixed-linked (FFL) specification in which communication and output-sharing groups are both linked and fixed across periods, a random-random-linked specification (RRL) in which communication and output-sharing groups are linked but randomized each period, 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.[2] Table 1 summarizes the five treatments in this experiment.

[2] Five possible combinations of our treatment factors are not tested in this paper. Linking fixed and random production groups and communication groups is not possible (FRL and RFL) and the remaining three (RFNL, FFNL and RRNL) were judged to be implausible in the context of CPR management.

Communication is introduced by way of a chat window that appears on the computer screens of the participants.[3] 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 private activity. Subjects then share their output from the common pool amongst all output-sharing group members and are given a summary providing their earnings for the period, the average earnings of others in their group and the average earnings of others outside of their group. 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. 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.[4]

We analyze group and individual effort, relative rents and dispersion of payoffs by treatment. We also code and analyze the content of the chat messages, and evaluate how each type of message might influence individual effort.

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[3] Bochet et al. [3] compare different forms of communication in public goods laboratory experiments and find little difference between the effects of face-to-face communication and verbal communication through a chat room.

[4] Groups used up to 234 seconds, 178 seconds, 177 seconds and 118 seconds respectively 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.

2.1. Treatments R and F

Our parameterization is the same as that used by Schott et al. [19]. Each participant is endowed with 28 units of effort to allocate to appropriation from the common pool resource or to an activity which pays a return of 3.25 lab dollars for each unit of effort. For this parameterization a group size of four is optimal in that the Nash equilibrium for three equal-sized groups of four coincides with the surplus-maximizing allocation of effort. There is no unique equilibrium allocation of effort for any member of a group, but there is a unique group Nash equilibrium allocation of 52 units of effort to appropriation from the common pool (equilibrium system effort is 156).[5]

Treatments R and F differ in how participants are assigned to output-sharing groups. Although theory offers no prediction on the effect of group assignment, Schott et al. [19] 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. These results might change when within-group communication is introduced.

2.2. Treatments RRL, FFL and FRNL

[5] See section 1 of Appendix I for a derivation of the equilibrium results. See Schott et al. [19] for the derivation of the optimal effort to allocate to appropriation from the common pool.

The parameters underlying Treatments RRL, FFL and FRNL are identical to those for Treatments R and F. Communication is non-binding, so the stage-game Nash equilibrium is unchanged. We note, however, that communication typically helps individuals in groups to coordinate their efforts, overcoming the tendency to shirk in public good environments and helping them to reduce excess effort in simple CPR environments [14,16]. 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 have the means to co-ordinate their actions while competing against other groups to obtain a larger share of the system output.

In the extreme case of perfect group co-ordination the individual group optimization of profit can be found by aggregating equation (2) across the four members of the group and differentiating it with respect to group output. In this case, the unique Nash equilibrium effort for each group is 78. There is no unique Nash equilibrium level of individual effort. Note that when the output-sharing groups compete against each other as groups, aggregate system effort is predicted to rise from the optimal level of 156 to 234.[6]

3. EXPECTATIONS REGARDING EFFORT

3.1. Treatments R and F

[6] See section 2 of Appendix I for this derivation.

Given the parameterization of the common-pool resource environment introduced in Section 2, we expect that each of the three four-person output-sharing groups will supply 52 units of effort. The system effort will be 156 units. This is true for both Treatments R and F.

3.2. Treatments RRL, FFL and FRNL

If communication groups and output-sharing groups are linked (Treatment RRL and FFL) the effect of output sharing may diminish. This will occur if individual players act co-operatively to increase group payoff. This suggests that under Treatments 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, because group members in the RRL treatment receive different feedback every round from new group members and, therefore, will find it more difficult to form consistent expectations about the coordination of effort among group members.

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, which would achieve the most efficient ($13 \times 12 = 156$) and equitable solution. 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 constantly randomized output-sharing groups. Treatment FRNL may be more likely to induce shirking compared to the other communication treatments because participants will have a weaker incentive to focus on group output maximization than on system output maximization.

The following expectations result from the discussion above:

Expectation 1: Effort will not differ between Treatments R and F.

Expectation 2: Effort will be greater in Treatments FFL and RRL than in Treatments F and R.

Expectation 3: Effort will be the same in Treatments FRNL as in Treatments F and R.

Expectation 4: Effort will be greater in Treatment FFL than in Treatment RRL during early periods of a session.

Expectation 5: The difference in effort under Treatment RRL and Treatment FFL will tend to narrow over time.

4. RESULTS

A total of 240 subjects participated in the experiment. There were four sessions in each of the five treatments. In each session, three groups of four subjects participated in 15 decision rounds after three practice rounds. Laboratory currency was converted at the exchange rate of 200 Lab dollars for 1 Canadian dollar. 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 treatments without communication and within 90 minutes in treatments with communication.

Table 2 summarizes mean system effort. There is one observation in each session. Table 2 also provides numerical predictions based on the expectations discussion in Section 3 above. A Kruskal-Wallis test indicates that there is a statistically significant difference among the 5 treatments (p-value = 0.0073 for mean system effort).[7]

4.1. Aggregate effort

For Treatments F and R, the Nash equilibrium for players maximizing individual payoffs predicts system effort of 156 units and individual session payoff of L$4217. The actual system efforts in both treatments are not significantly different from the predictions (sign test, two-sided, n = 4, p-value = 0.625 for mean system effort in both treatments). There is also no significant difference between Treatments F and R (Mann-Whitney U test, p-value = 1, n = m = 4).

Result 1. *When there is no communication, the mean system appropriation effort is consistent with the equilibrium prediction of individual optimization.*

[7] 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.

Group assignment (fixed versus random) makes no difference. These are identical to the results documented in Schott et al. [19].[8] *This evidence supports Expectation 1.*

When pre-play non-binding communication is allowed (under Treatments FFL, RRL and FRNL), system effort differs significantly from that of the no-communication treatments (Mann-Whitney U test, p-value = 0.0026, n = 8, m = 12). 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-Whitney U test, p-value = 0.0209, $n = m = 4$). While the median system effort in FFL is not significantly different than 234 units, the median 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.[9]

Result 2. *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*

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[8] We used data from Schott et al. [19] for 3 of our 4 sessions for Treatments F and R. We have added an additional replication of F and R treatments for this paper that were not reported in Schott et al. [19] in order to increase accuracy and provide symmetry to the three communication treatment sessions. Results from the new replications confirm the robustness of results reported by Schott et al. [19].

[9] The null hypothesis that the median system effort in FFL is equal to the predicted value of 234 units cannot be rejected (sign test, two-sided, p-value = 0.6250, n = 4). However, the null hypothesis that the median 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 (sign test, one-sided, p-value = 0.0625, n=4). The null hypothesis that the median system effort in RRL is equal to 156 can be rejected in favor of the alternative that it is more than 156 (sign test, one-sided, p-value = 0.0625, n=4).

random linked group assignment (Treatment RRL), fixed linked group assignment (Treatment FFL) leads to better coordination and thus significantly more appropriation effort. This evidence supports Expectation 2.

While communicating groups linked to output-sharing groups are better able to coordinate than groups who may not communicate, this is not true when stable communication groups share output with a different group each round (Treatment FRNL). When communication and output-sharing groups are not linked, appropriators coordinated no better than in the no communication treatments. System effort for Treatment FRNL is not significantly different from the predicted individual-optimization level of 156 units (sign test, two-sided, *p*-value = 0.6250), nor from the actual system effort from Treatment R (Mann-Whitney U test, p-value = 0.3865, n = m = 4), nor from the actual system effort from Treatment F (Mann-Whitney U test, p-value = 0.1489, n = m = 4).

Result 3. *When communication and output-sharing groups are not linked, communication is not able to effectively facilitate coordination among group members. Effort devoted toward appropriation is not increased over that in the no-communication, output-sharing treatments. This evidence supports Expectation 3.*

The data support our expectation that communication within output-sharing groups will increase system effort. This suggests that communication among group members is counteracting the free-riding incentives provided by output sharing. Moreover, the offset effect is much larger when appropriators are communicating and sharing output with the same group of participants 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. Expectations 4 and 5 imply that we should find positive differences between mean effort in FFL and mean effort in RRL early in the sessions and that over time, these differences will narrow. This pattern of behavior will be consistent with the FFL-RRL effort differences being positive and falling over time, but never becoming negative. Convergence of FFL and RRL effort is possible if with enough experience, linked groups, even if randomly assigned period after period, eventually behave in the same way. We can capture this behavior by fitting the function $y = a + b(1/t)$, where y is the difference between mean effort in the four sessions of Treatment FFL on the one hand and the four sessions of Treatment RRL on the other. We expect that $a= 0$ and $b > 0$. When $t = 1$, b is the initial positive gap between FFL and RRL effort and as t gets larger and larger, $b(1/t)$ goes to zero and the effort gap goes to zero. Figure 2 presents the differences between the mean effort levels shown in Figure 1 for Treatments FFL and RRL and includes an estimated trend line based on the relationship $y = a + b(1/t)$. We can reject the null hypothesis that $a = 0$ in favor of the alternative that $a \neq 0$ but we cannot reject the null hypothesis that $b = 0$ in favor of the alternative that $b > 0$. [10]

[10] The results of an OLS regression give $a = 53.88$ with a standard error of 6.89 and $b = -56.62$ with a standard error of 21.22. The null hypothesis that $a = 0$ can be rejected in favor of the alternative that $a \neq 0$ ($p = 0.000$). The null hypothesis that $b = 0$ can not be rejected in favor of the alternative that $b > 0$ ($p = 0.980$).

Result 4. *Group assignment has a significant impact on appropriation effort when output-sharing and communication are linked. Members of fixed output-sharing groups coordinate much more effectively than do members of random output-sharing groups. This result persists through the 15 rounds of the laboratory sessions. This evidence supports Expectation 4 but does not support Expectation 5.*

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. We adopt the coefficient of variation of individual payoffs (CoV) as our indicator of equity and income at the socially efficient level as a benchmark for income comparisons. With output sharing in groups of four and the socially efficient effort of 52 units per group, the mean individual payoff is 281.49 lab dollars per period or 4222 for the entire session of 15 periods.

Table 3 reports the means and CoVs of individual payoffs. There is one observation per session. An OLS regression with robust standard errors indicates significant differences between the mean CoVs across treatments. The smallest CoV is observed in Treatment FRNL while the biggest is in FFL (Table 4).[11] Pairwise comparisons of the

[11] The mean CoV in Treatment FRNL is significantly different from Treatment F, R, FFL and RRL (t test, *p*-value = 0.0002, 0.0114, 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

mean CoVs between treatments indicate significant differences between all paired treatments except Treatments RRL and R. With linked communication groups the distribution of 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 (FRNL), payoffs are most equitably distributed among the five treatments and payoffs are significantly greater than those realized by participants in all other communication treatments. This equity in payoffs is consistent with our earlier conjecture that the FRNL treatment would provide an incentive for communication groups to discuss playing the symmetric socially optimal individual contribution of effort ($x_i = 13$). This also supports the conjecture in Schott et al. [19] that random output-sharing groups would likely be more desirable than fixed output-sharing groups in an environment involving communication. Furthermore, communication that is not linked to output-sharing has the positive effect of reducing income inequality. Because FRNL is not significantly different from R and F in terms of efficiency, communication in social groups and random output-sharing outside of social networks might be the most desirable output-sharing environment.

Nonparametric tests on mean individual session payoffs, whose distributions are presented in Figure 3, 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

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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).

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 lower than and 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 Treatments RRL and FRNL yield identical results: $n = m = 4$, p-value = 0.0209). The mean individual session payoffs in FFL are significantly less than in RRL (Mann-Whitney test, n=m=4, p-value = 0.0209).

5. CONTENT ANALYSIS AND EFFORT

We have found that allowing non-binding communication increases effort when communication and output-sharing groups are linked and especially when the composition of the groups is fixed. We now investigate how communication is shaped by the rules for linking and remixing the output-sharing groups, hoping to discover the forms of communication that are most effective in coordinating behavior. To do this we conduct a detailed analysis of the content of the chat messages.

5.1. Coding the messages

Following Zhang [22] we organized the chat transcripts into coded-message units.[12] After examining a small sub-sample of messages we identified the 14 non-exclusive categories listed in Table 5. Two coders who were not otherwise involved in the analysis of the data from this experiment independently coded all messages according to the 14 categories. [13] Each message can be coded under as many or few categories as the coders deem appropriate.

Table 5 summarizes the relative frequency of coded-message units by category along with Cohen's Kappa statistic.[14] All of the measured Kappas are significantly greater than 0. Only three of the 42 Kappa estimates for Categories 4, 9, and 10 in Treatment FRNL indicate less than moderate agreement. Messages in these categories occurred with very low frequencies (2.1%, 1.83%, and 0.94% of messages sent). We have no conjecture for why these categories exhibited such low agreement in this particular treatment (the mean Kappa exceeds 0.55 for these same three categories in both Treatments RRL and FFL).

5.2 Volume of Messages by Category and Treatment

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[12] A coded-message unit consists of the information submitted by a participant to the other members of the participant's group during one communication sequence. A sequence starts when the participant begins typing a message and ends when the participant hits the "enter" button on the keyboard to submit the message to the group.

[13] A variable for each category records whether any specific message-unit has been classified to that category. A message is coded as 1 in any given category if it is deemed to fit into that category and 0 otherwise. If the two coders disagree on classification to a specific category, the corresponding variable is coded as one-half.

[14] The Kappa statistic measures the degree of agreement between two coders above that expected by chance. It has a maximum value of 1 when agreement is perfect, 0 when agreement is no better than by chance and it takes negative values when agreement is less than by chance. The general conventions regarding the interpretation of other values are as follows: $0 < K \leq 0.20$ is poor agreement, $0.20 < K \leq 0.40$ is fair agreement, $0.40 < K \leq 0.60$ is moderate agreement, $0.60 < K \leq 0.80$ is good agreement and $K > 0.80$ is very good agreement [15].

The volume of messages is clearly different across treatments. Treatment RRL (linked groups with random reassignment) has most messages (3218), Treatment FFL has fewer (2752) and the unlinked Treatment FRNL has the fewest messages (1808). These differences are highly significant ($\chi^2 = 398$, df = 2, $p < .001$) and are consistent with the nature of the communication regimes. In Treatment RRL agreements must be renegotiated with a new group each period. Fewer messages are required in Treatment FFL because agreements can be carried over relatively easily from period to period. Treatment FRNL prevents subjects from communicating with their specific output-sharing group. Consequently communication may have been viewed as futile.

There are interesting variations by treatment in the distribution of messages across categories. Table 5 reports and Figure 4 illustrates these distributions. Categories 3, 5 and 7 are the top three categories to which messages are coded for each of the three treatments. Category 3 “Propose an amount to invest in market 2” is the modal category for Treatments FFL (29%) and RRL (32%) and second most frequently coded category for FRNL (21%). Category 7 “Talk about the investment decisions or payoffs made in the previous rounds” is the modal category for Treatment FRNL (27%). This is the third most frequently coded category for Treatments FFL (16%) and RRL (11%). Category 3 “Agreement” is the second most coded category for all three treatments and varies from 21% to 23% (not very different across treatments).

Categories 2 and 8 “Ask/inquire/clarify proposals of other group members” and “Talk about the conflict/competition/coordination” are the fourth and fifth most often coded messages. The former exceeds 10% only for Treatment RRL (10.4%) and the latter exceeds 10% only for Treatment FFL (12.8%). None of the other categories are associated with more than 9% of the messages (the largest is Category 13 "Others" which is recorded 8.8% of the time).

Discussion frequently focuses on proposals to coordinate effort to appropriation when communication groups and output-sharing groups are linked. When these groups are not linked, these messages occur less often, most likely because they cannot be directed to output sharing group members, and discussion focusing on experiences from previous rounds takes up more of the chat time.

5.3 Aggregate Volume of Messages and Effort

We now investigate whether there is any systematic relationship between the aggregate number of messages in a period and the amount of effort expended on appropriating the common pool resource in that period. We investigate the relationship between effort and specific categories of messages in the next section. We investigate both simple correlations between chat messages and effort and regression models which control for changes in message activity over time.

The relationship between the chat variables and individual effort within the group is probably bi-directional. That is, the number and content of chat messages may influence the level of group effort and also the level of group effort may influence the number and content of messages in later periods. This is most likely to be true when the composition of communication groups is fixed across periods. To avoid this issue of causality we first examine the simple correlations between individual effort per period and the total number of messages. We adopt the Kendall Tau Rank Correlation coefficient, which is a non-parametric measure of association between observations on two variables. This coefficient is computed by classifying every possible pair of observations as concordant (ranked the same on both variables) or discordant (ranked differently on the two different variables) and expressing the difference as a fraction of the total number of pairs. A value of 1 implies that every pair of observations is concordant, -1 implies that every pair is discordant, and 0 implies that half the observations are discordant and half concordant.[15] The Kendall Tau correlation coefficients and associated p-values are presented in the first row of Table 6.

Table 6 shows immediately that the total number of messages seen by an individual is not significantly correlated with effort in any treatment. This is not the entire story, however, because both the overall volume of messages and their relation to effort may be changing over the course of the session. To address this we estimate the linear regression model reported in Table 7. This model interacts a trend variable (inverse period) with aggregate message volume. Overall there is a highly significant positive relationship between the volume of messages and the level of individual effort, suggesting that coordination is indeed promoted by communication. There is a very interesting negative interaction between volume and inverse period, especially for the fixed communication group Treatments FFL and FRNL. This negative interaction outweighs the positive main effect of volume, so that the estimated relationship between total volume and message volume is negative in Period 1 for both Treatments FFL and FRNL. By Period 2, however, the estimated relationship is clearly positive for both Treatments. We conclude

[15] The quantity (1 + tau)/(1 – tau) is the odds ratio (probability of concordance)/(probability of discordance).

that early in the session high message counts indicate a group which is having a hard time coming to an agreement, while later in the session a high message count is associated with maintaining the coordination that has already been achieved.

Result 5. *In general there is a strong positive relationship between the total volume of messages and the level of appropriation effort. However the relationship is negative in Period 1 for Treatments with fixed communication groups.*

5.4 Specific Categories and Effort

Tables 6 and 7 also report on the relationship between effort and messages in specific categories. The Kendall tau coefficients for Treatment FFL show that individual effort is significantly and negatively correlated with the volume of messages in Categories 1, 2, 7, 10, 11 and 12 (messages focusing on initiating discussion, clarification of proposals, effort and payoffs in previous rounds and negative talk about the group). Effort is significantly and positively correlated with Categories 9 and 14 (messages focusing on positive talk about the group and noting the last round). There are no other significant correlations. While correlations with most of these categories may be subject to reverse causation in fixed groups (i.e. previous effort affecting messages), it is likely that messages asking group members to clarify their proposals (Category 2) are associated with poor group coordination and likely the cause of significantly reduced effort levels.

Simple correlations in Treatment RRL are less likely to be the result of reverse causation than those in Treatments FFL because the groups are remixed each period.

Consequently the actions in previous periods have no direct relevance to the groups in the current period. There are only three significant simple correlations. Individual effort is positively correlated with talk about previous rounds and positive talk about the group (Categories 7 and 9) but is negatively correlated with talk of luck or random play (Category 12). In Treatment FRNL only message Category 13 (other miscellaneous messages) is significantly correlated with individual effort.

As with total volume, the effects of individual categories of messages may be masked by within-session trends in the volume of messages. To investigate this effect we report in Table 8 estimated coefficients for a random effects panel model regressing individual effort levels on communication message categories in each period for each of the three communication treatments. The estimation assumes random effects at the subject level to account for correlation among effort decisions made by each subject and uses robust standard errors to correct for possible heteroskedasticity across subjects. The assumption of random-effects at the individual level fits the experimental context well, for any subject-specific effects (individual heterogeneity) are independent of changes in the experimental treatments (exogenous regressors). In addition to the message category variables in the model we include a trend variable (inverse period) and lagged variables for the total effort of others in the same group and total effort of others in other groups. These lagged variables allow us to control for the impact of past decisions of others within and outside of output-sharing groups in different communication environments. Note that these regressions necessarily omit the first period.

Table 8 shows that the trend variable is not significant in any treatment. The lagged variables are significant only in the FFL treatment. This is as expected since in both other treatments output-sharing groups were remixed each period. Rational subjects would not be expected to respond to decisions made in previous groups under such conditions. In the FFL treatment individual effort is positively related to the past contributions by others in the same group but negatively related to past contributions made by others in different groups. This suggests that, independent of the communication content, subjects raise their own effort levels when others in the group raise theirs (consistent with a tit-for-tat or reciprocity strategy) but respond by lowering effort if other groups are raising theirs. The latter is a best response strategy when groups are already contributing more than the socially efficient effort level, which is the case for the FFL treatment.

The effect of different types of message varies by treatment. Messages directly associated with negotiation of effort levels (Category 3 – Proposals – and Category 2 – Clarifications) are strongly significant in the fixed, linked group Treatment FFL but not in the others. Note that the partial effect of clarification is negative. Frequent proposals will not increase effort if the other subjects are questioning them. Messages signifying agreement with a proposal were positively and significantly associated with effort in both the linked Treatments (FFL and RRL) but not in the unlinked Treatment (FRNL). Messages associated with group spirit (Category 9) and discussion about previous decisions and strategy (Categories 7, 8) are positively associated with effort in Treatment RRL, while talk about the game rules (Category 11) is negatively related to effort. These categories are not significant in any of the other treatments. In Treatment FRNL none of the message categories was found to be significant at a 5% level.

Result 6 *The effect of specific messages on coordination of individual effort varies across treatments. In Treatment FFL messages related to negotiation of* *proposals are most effective. In Treatment RRL messages related to strategy and group identity are most effective in raising effort. In Treatment FRNL no messages are effective in raising effort.*

To summarize, our content analysis shows that the rules regarding communication protocol have a powerful effect on the nature of the communication and its effectiveness in coordinating group behavior. Treatment FFL allowed the most successful coordination. Because groups were fixed the results of negotiation could be carried across periods, so fewer messages were needed than in the second most coordinated treatment, RRL. Because group identity was known and formed, messages in Treatment FFL could focus on specific proposals for effort and signaling agreement with these proposals. In this treatment there is a clear positive association between specific proposals and greater coordination (signaled in this experiment by higher individual effort levels).

Treatment RRL allowed the second most coordination. Because groups were remixed every period, group agreements had to be renegotiated every period. This led to a high total volume of messages. Discussion of specific proposals dominated the communication in this treatment, to an even greater extent than in Treatment FFL. It is fascinating to note, however, that under these conditions a high frequency of proposals and agreement was not sufficient to guarantee higher coordination. Instead, messages related to game rules, strategy and group identity were most clearly associated with increased effort. Although their relative frequency was no greater than in Treatment FFL, these messages appear to have played a major role in creating a sense of group identity in Treatment RRL.

Treatment FRNL exhibited the lowest efforts, least coordination, and least communication. Discussion in this treatment shifted away from specific proposals, which were irrelevant when the communication group was not linked to the output-sharing group, and focused more on what had happened in previous rounds. Such discussion was not effective in promoting coordination in the output-sharing groups.

6. DISCUSSION AND CONCLUSIONS

We have investigated the effect of alternative structures for communication on the performance of output-sharing partnerships exploiting a common pool resource. Our group size was chosen so that within-group shirking incentives would precisely offset between-group over-harvesting incentives and the Nash equilibrium would be socially optimal. In our baseline, no-communication treatments, aggregate effort was not significantly different from this efficient Nash equilibrium. In our other treatments we found that non-binding within-group communication was sufficient to reduce the within-group shirking incentive and to lead to an over-harvesting equilibrium provided communication groups were linked to output-sharing group. The effect was greatest when group communication remained constant over the experiment. When communication and output-sharing groups were not linked there was no significant effect of communication.

The volume and content of messages are affected by the communication structure. Messages are most frequent when teams are linked but remixed every period. In general a high volume of messages is associated with a higher level of effort, but this is not true of early periods when communication groups are fixed. In this case high message volumes may be an indicator of lack of coordination. When groups are linked and fixed, messages associated with direct negotiation of effort levels are significantly associated with high effort levels. When groups are linked but remixed each period messages related to identifying the group's interests and promoting group identity are significantly associated with higher effort levels.

Our experiment is similar in spirit to that conducted by Sutter and Strassmair [21]. Like us, Sutter and Strassmair study the effect of communication on a competition between teams, in their case between two teams of three members competing to win a tournament where the prize is a transfer from the team with lower effort to the team with higher effort.[16] The prize introduces an incentive to increase effort beyond that which would maximize the team's profit. This is similar to the over-harvesting incentive in our CPR. As in our experiment, there is a free-riding incentive operating within the team which tends to reduce the team's effort. Unlike us, Sutter and Strassmair treat increases in effort as beneficial. Our finding that within-group communication reduces efficiency in the linked group treatments is consistent with Cason et al.'s [4] findings in a weakest-link tournament game.[17]

Like us, Sutter and Strassmair analyze the effect of varying communication protocols on aggregate effort and on the composition of messages. Their treatments are within-group communication (present or absent) crossed with between-group communication (present or absent), always in a "partners" environment. In contrast, we allow only

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[16] Actually, the prize goes to the team with highest output, which depends on aggregate effort plus a random disturbance, but this complication can be ignored for our purposes.

[17] Cason et al. [4] report that within-group communication not only leads to greater coordination and more aggressive competition, but also reduces efficiency significantly in a weakest-link tournament game.

within group communication but examine both “partners” and “strangers” treatments (FFL and RRL respectively). Our third communication treatment (FRNL) introduces some aspects of inter-group communication, however, because the communication group is separate from the output-sharing group.

Sutter and Strassmair find that the difference between the lagged own group effort and lagged other-group effort is generally significant. We support this finding for partnered groups (Treatment FFL) but not for stranger groups (Treatment RRL). We confirm Sutter and Strassmair’s observation that communication with people outside of one's own team does not affect individual behavior (Treatment FRNL), but in our case teams are strangers not partners when they communicate with people outside of their group. One would expect that strangers had a bit more of an incentive to influence others not in their groups through communication as one might be matched up with them later on in the experiment. We also found that our groups focused on very different communication topics. In Sutter’s and Strassmair’s experiment, groups were much more concerned about unequal efforts within their team and appeals to fairness. In none of our groups was equity a major discussion topic. This seems to suggest that communication contents and consequently behavior are influenced by the specific task and the information provided to subjects. Like Sutter and Strassmair, however, we observe major shifts in the composition of messages across the various categories in response to changes in treatment.

More generally, we have contributed to the literature on communication and competition among teams by extending the domain of interest to include common pool resources. In addition, we have shown that the structure of communication – whether production teams and communication groups are linked, for example – is critical to understanding the effects of communication in these environments.

At the policy level, our results show that communication within output-sharing groups poses a real problem for this form of resource management. Communication within output-sharing groups is to be expected if the groups are based in small communities and group members are well-known to each other. This problem could be tackled in two ways. First the size of the output-sharing groups could be increased beyond the optimal size for non-communicating groups. Schott et al. [19] have shown that effort significantly diminishes with group size; presumably the same is true for the effectiveness of cheap talk in preventing shirking incentives. A second strategy is to unlink communication and output-sharing groups by having an agent assign output-sharing group membership randomly and anonymously, remixing the groups at regular intervals. Communication under these circumstances might actually be beneficial since we have shown that it significantly reduces income inequality without affecting efficiency.

This paper has focused on the effects of within-group communication. Further research could usefully investigate the effect of allowing inter-group communication in the manner used by Sutter and Strassmair. Those authors found that inter-group communication significantly reduced the effects of the effort-inducing between-group competition. It would be interesting to see if communication among all groups would refocus interest on the interests of all participants at once, leading to reduced harvesting, or whether inter-group communication could be used strategically by members of an output-sharing group to induce other groups to reduce their effort without reciprocal action by the first group.

In the environment we have presented, an outside agency establishes output-sharing groups as a means to manage the CPR. A further extension of this work could examine the role of communication and output-sharing in an environment with endogenous group formation or in an environment with communication in which the appropriators are able to design and implement the control mechanism. Resource users could, for example, either vote on the optimal size of output-sharing groups or an outside mediator could simply suggest the optimal group size (as suggested by Heintzelman et al. [10]). Pre-play communication furthermore has been shown to induce subjects to pursue the payoff-dominant strategy (see for example Cooper et al. [6]). Will output sharing prevail 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 groups evolve with the correct group size for the effects different communication environments create and will there be a role for randomly assigned output-sharing groups in this environment? These research questions are relevant not only in the area of the provision of public goods and harvesting resources from a common pool, but also for competition in oligopolistic markets and the efficient supply of effort by teams in large corporations.

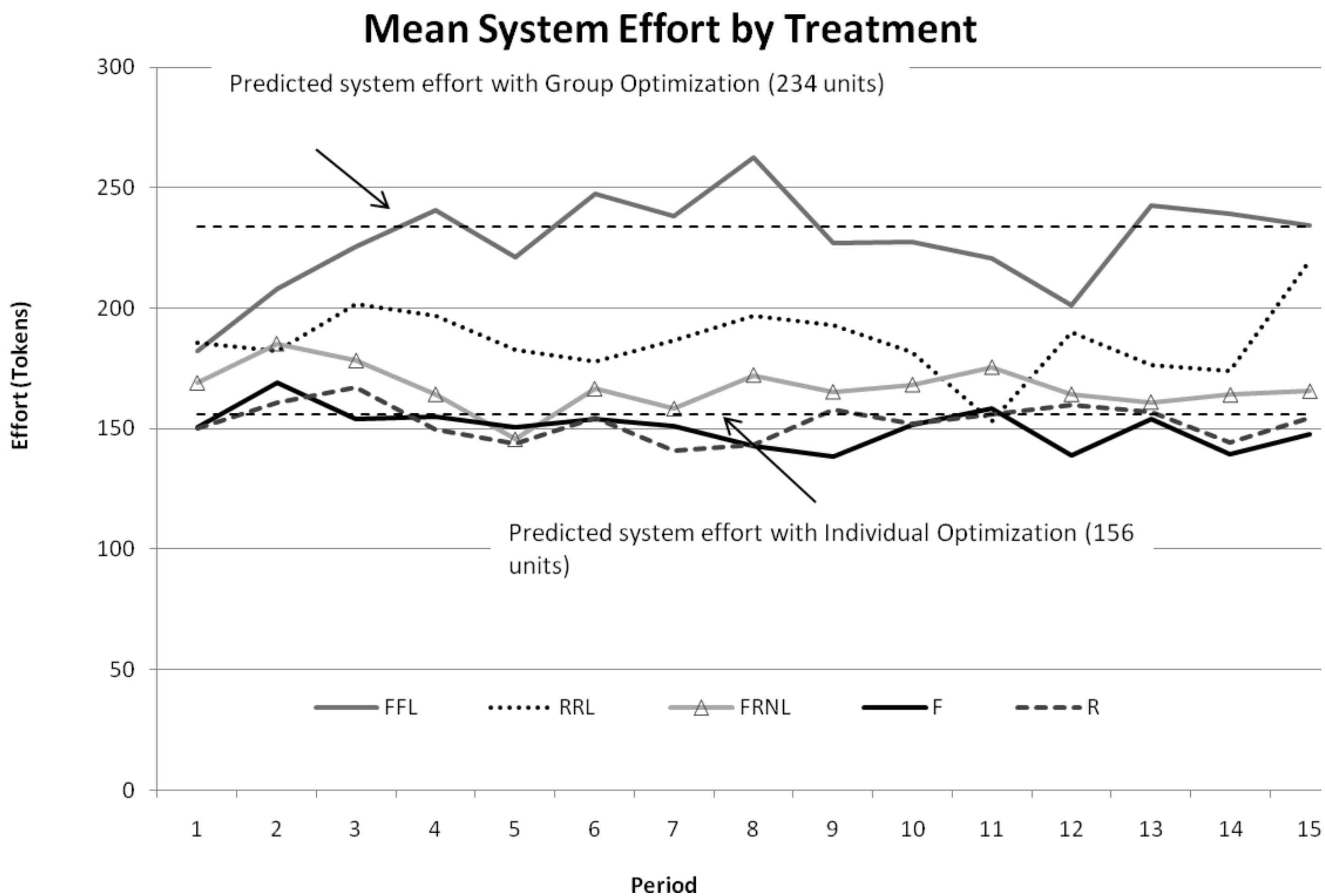

Figure 1. Mean system effort allocated to appropriation from the common pool

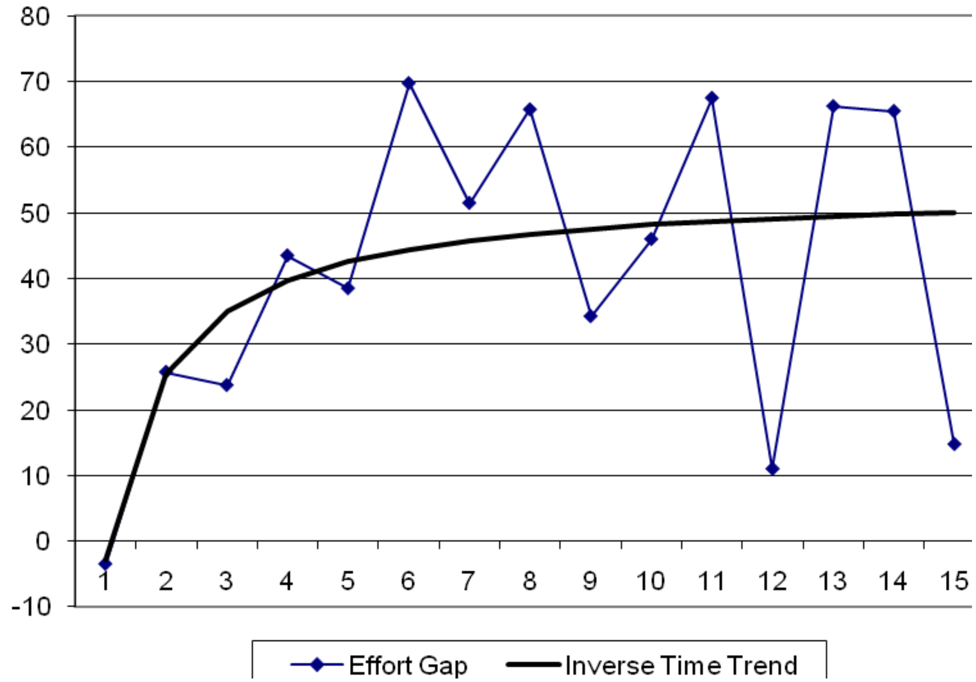

Figure 2. Mean FFL Effort less Mean RRL Effort by Period and Inverse Time Trend Line

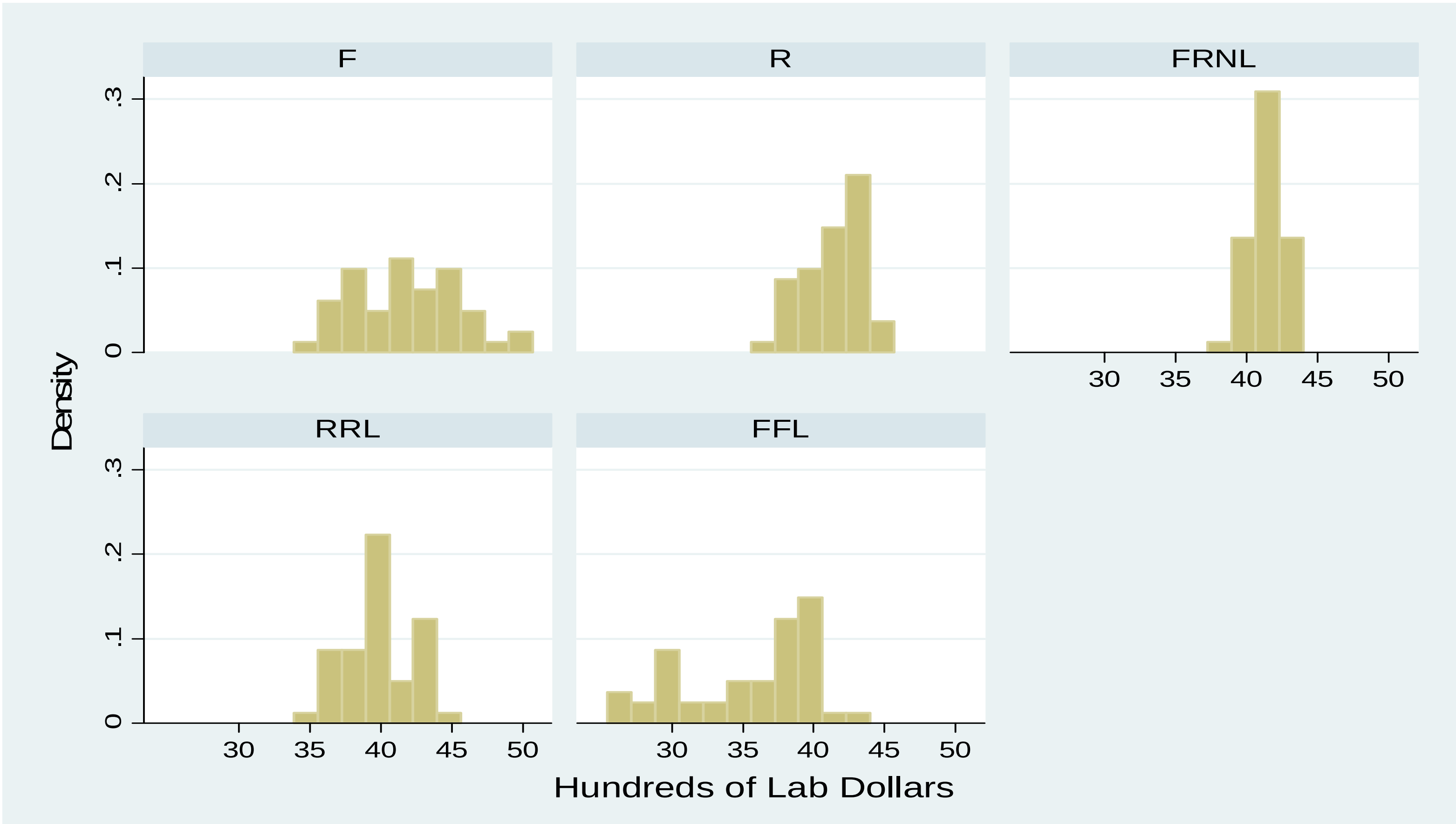

Figure 3. Distribution of individual session payoffs by treatment

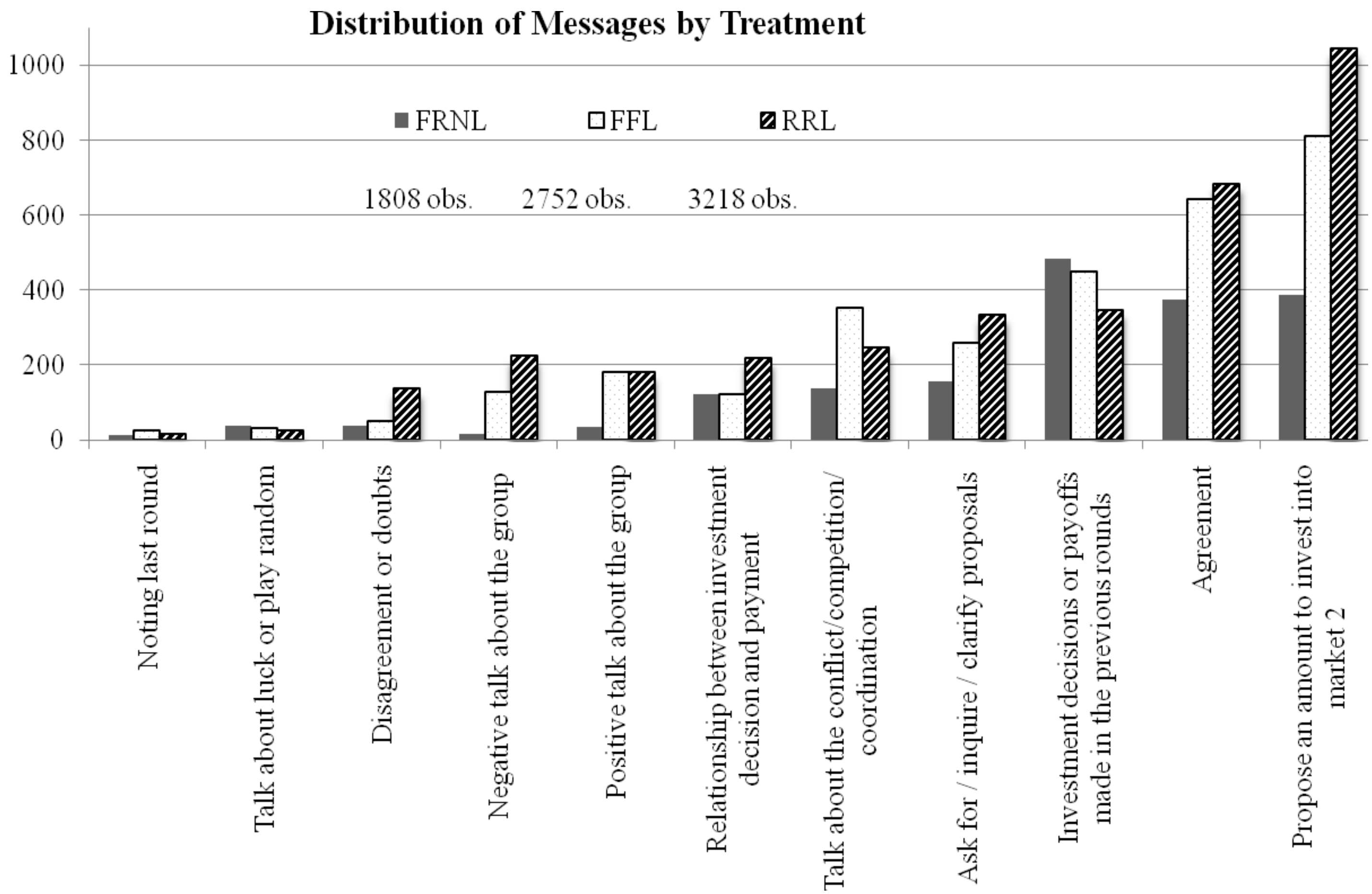

Figure 4. Distribution of communication messages by treatment

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 per session by treatment

Treatment	F	R	FRNL	RRL	FFL
Predicted system effort	156	156	156	156-234	234
Mean system effort	150.40 (7.38)	152.77 (20.27)	166.87 (17.21)	186.57 (10.90)	227.92 (6.97)

Notes: Standard deviations of the session means are in parentheses. The means and standard deviations are based upon four observations for each treatment.

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

Treatment	F	R	FRNL	RRL	FFL
Mean individual session payoff in lab dollars	4174.26 (21.67)	4147.10 (33.99)	4137.98 (42.90)	3989.53 (61.51)	3528.27 (123.95)
Mean coefficients of variation	0.09 (0.03)	0.05 (0.01)	0.03 (0.01)	0.06 (0.01)	0.13 (0.02)

Notes: Standard deviations of the session means 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; *** significant at 1%, ** significant at 5%, * significant at 10%.

Table 5. Reliability indexes and frequency of message coding by treatments

Code	Category Description	FRNL (1808 units) Kappa	FRNL (1808 units) Relative frequency	RRL (3218 units) Kappa	RRL (3218 units) Relative frequency	FFL (2752 units) Kappa	FFL (2752 units) Relative frequency
C1	Initiating discussion	0.97	6.14	0.93	6.67	0.81	1.05
C2	Ask for / inquire / clarify proposals of other group members	0.57	8.63	0.62	10.35	0.56	9.34
C3	Propose an amount to invest into market 2	0.79	21.40	0.72	32.40	0.76	29.41
C4	Disagreement or doubts	0.33	2.10	0.55	4.20	0.48	1.72
C5	Agreement	0.84	20.77	0.77	21.24	0.79	23.28
C6	Talk about the relationship between investment decision and payment	0.46	6.78	0.58	6.76	0.52	4.35
C7	Talk about the investment decisions or payoffs made in the previous rounds	0.80	26.80	0.63	10.77	0.62	16.28
C8	Talk about the conflict/competition/ coordination	0.51	7.61	0.52	7.61	0.60	12.81
C9	Positive talk about the group (e.g., team work and group spirit, loyalty, honesty, equity)	0.26	1.83	0.52	5.59	0.62	6.53
C10	Negative talk about the group (e.g., distrust, dishonesty, defection)	0.11	0.94	0.63	6.91	0.56	4.64
C11	Talk about the game rules (e.g., conversion rate, grouping; what can be revealed in the chat)	0.63	6.91	0.45	8.45	0.44	6.17
C12	Talk about luck or play random	0.75	2.05	0.57	0.70	0.87	1.14
C13	Others (e.g., humor, time, comments)	0.47	7.44	0.61	7.27	0.57	8.77
C14	Noting last round	0.59	0.75	0.83	0.45	0.55	0.86

Notes: Relative frequency is the number of messages coded in a category divided by the total number of messages recorded in a treatment times 100. The sum of the relative frequency can be greater than 100 because some messages are assigned to several categories. Messages coded as Category 2 do not specifically refer to a contribution level. For each category, the p-value is less than 0.005 for the relevant Kappa. These p-values are the probabilities of incorrectly rejecting the null hypothesis that coder agreement is no better than chance.

Table 6. Kendall Tau Correlation Coefficients: Individual Effort versus Number of Messages (probability of making an error by rejecting null that coefficient is equal to zero)

	Treatment		
Message Type	FFL	RRL	FRNL
Total Messages	-0.035 (0.207)	0.002 (0.935)	0.041 (0.172)
C1:Initiating discussion	-0.071 * (0.023)	0.042 (0.168)	0.005 (0.868)
C2:Ask for / inquire / clarify proposals of other group members	-0.136 * (0.000)	-0.055 (0.058)	0.023 (0.452)
C3:Propose an amount to invest into market 2	0.020 (0.484)	0.011 (0.678)	0.055 (0.061)
C4:Disagreement or doubts	-0.057 (0.065)	-0.014 (0.644)	0.000 (0.988)
C5:Agreement	0.049 (0.081)	0.008 (0.775)	0.012 (0.694)
C6:Talk about the investment decision and payment relationship	-0.028 (0.350)	0.027 (0.369)	0.050 (0.102)
C7:Talk about the investments or payoffs made previously	-0.094 * (0.001)	0.060 * (0.040)	-0.003 (0.913)
C8:Talk about the conflict/competition/ coordination	0.052 (0.075)	0.014 (0.642)	-0.016 (0.597)
C9: Positive talk about the group	0.133 * (0.000)	0.103 * (0.001)	0.031 (0.318)
C10:Negative talk about the group	-0.122 * (0.000)	0.033 (0.273)	0.033 (0.297)
C11:Talk about the game rules	-0.073 * (0.016)	0.010 (0.736)	0.029 (0.345)
C12:Talk about luck or play random	-0.120 * (0.000)	-0.080 * (0.010)	0.052 (0.096)
C13:Others	-0.032 (0.287)	-0.017 (0.567)	0.062 * (0.043)
C14:Noting last round	0.087 * (0.005)	0.041 (0.188)	0.036 (0.255)

Notes: Kendall Tau statistics that are significantly different from zero at the 5% level are marked with an asterisk.

Table 7. Effects of volume of messages on individual effort

Dependent Variable: individual effort			
Independent Variables	FFL	RRL	FRNL
Inverse period	0.35	-0.73	3.87**
	(2.64)	(2.39)	(1.95)
Volume of messages	0.15***	0.14***	0.16***
	(0.05)	(0.05)	(0.05)
Volume*inverse period	-0.27***	-0.08	-0.25**
	(0.10)	(0.08)	(0.10)
Constant	17.86***	13.54***	12.28***
	(1.01)	(1.08)	(0.63)
Observations	720	720	720
Number of individual	48	48	48

Notes: Robust standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%. All models include a random effects error structure, with the individual subject effects. The volume of the message is the total messages that an individual sent and received from his own group in a given period.

Table 8. Effects of various types of messages on individual efforts

Dependent Variable: Individual effort			
Independent Variables	FFL	RRL	FRNL
Inverse period	-2.82	-2.07	1.84
	(2.55)	(3.23)	(2.21)
Lagged period total contribution from others in the same group	0.12***	-0.01	0.02
	(0.02)	(0.02)	(0.02)
Lagged period total contribution from others in other groups.	-0.03**	0.01	0.01
	(0.01)	(0.01)	(0.01)
C1:Initiating discussion	1.74	0.42	0.13
	(2.58)	(0.31)	(0.28)
C2:Ask for / inquire / clarify proposals of other group members	-0.61***	-0.15	-0.07
	(0.17)	(0.23)	(0.19)
C3:Propose an amount to invest into Market 2	0.22***	-0.08	0.19
	(0.05)	(0.11)	(0.13)
C4:Disagreement or doubts	-0.52	0.09	-0.34
	(0.53)	(0.35)	(0.42)
C5:Agreement	0.20**	0.32**	-0.03
	(0.10)	(0.13)	(0.10)
C6:Talk about the investment decision and payment relationship	0.17	0.07	0.49
	(0.27)	(0.32)	(0.36)
C7:Talk about the investments or payoffs made previously	0.18	0.38**	0.02
	(0.13)	(0.16)	(0.10)
C8:Talk about the conflict/competition/ coordination	-0.15	0.69***	-0.26
	(0.14)	(0.25)	(0.26)
C9: Positive talk about the group	-0.17	1.12***	0.28
	(0.22)	(0.28)	(0.58)
C10:Negative talk about the group	-0.19	0.29	0.48
	(0.30)	(0.19)	(0.90)
C11:Talk about the game rules	0.30*	-0.76***	0.23
	(0.17)	(0.27)	(0.18)
C12:Talk about luck or play random	-0.80	-0.53	0.64*
	(0.53)	(0.92)	(0.38)
C13:Others	-0.15	-0.39*	0.13
	(0.16)	(0.21)	(0.19)
C14:Noting last round	0.18	0.99	0.66
	(0.69)	(0.98)	(0.60)
Constant	16.99***	11.74***	11.41***
	(2.57)	(2.06)	(1.45)
Observations	672	672	672
Number of individuals	48	48	48

Notes: Robust standard errors in parentheses. *** significant at 1%, ** significant at 5%, * significant at 10%. All models include a random effects error structure, with the individual subject effects. Variables C1-C14 are the volume of group messages by coding categories, i.e. the total messages exchanged within a group that fall into a given category.

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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) is

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

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) is

$$\pi = 3.25(28 - x) + \frac{1}{n}\frac{X_g}{X}Y ,$$

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

Differentiating π with respect to x and setting this equal to zero yields

$$-3.25 + 3.25\frac{1}{n} - 0.09375\frac{1}{n}(X + X_g) = 0 .$$

This reduces to

$$X + X_g = (32.5 - 3.25n)\frac{1}{0.09375} .$$

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

$$X + {}^{m}X_g = \frac{(32.5 - 3.25n)}{0.09375} ,$$

where m is the group identifier.

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

$${}^{m}X_g = \frac{32.5 - 13}{0.09375} \times \frac{1}{4} = 52 .$$

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 equals a unique value. There is a unique group Nash equilibrium allocation of effort to appropriation from the common pool. In this case, the unique group Nash equilibrium amount of effort is 52. The system effort is 156.

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) is

$$\pi = 3.25(28 - x) + \frac{1}{n}\frac{X_g}{X}Y .$$

Profit for the group is

$$\pi_g = 3.25 \times 28n - 3.25X_g + 32.5X_g - 0.09375XX_g .$$

Differentiating π_g with respect to X_g and setting this equal to zero yields

$$X + X_g = \frac{29.25}{0.09375} .$$

When there are twelve appropriators from the common pool and $n = 4$, there are three output-sharing groups and $x = 3X_g$, therefore

$$X_g = 78 .$$

The Nash equilibria in the situations described above result in the following values. 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 equals a unique value. There is a unique group Nash equilibrium allocation of effort to appropriation from the common pool. In this case the unique group Nash equilibrium amount of effort is 78. The system effort is 234.

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. 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.

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 labeled "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.*[18] 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.
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.

[18] In Treatments RRL and FFL, the sentence in italic is removed.

APPENDIX III

SCREEN SHOTS

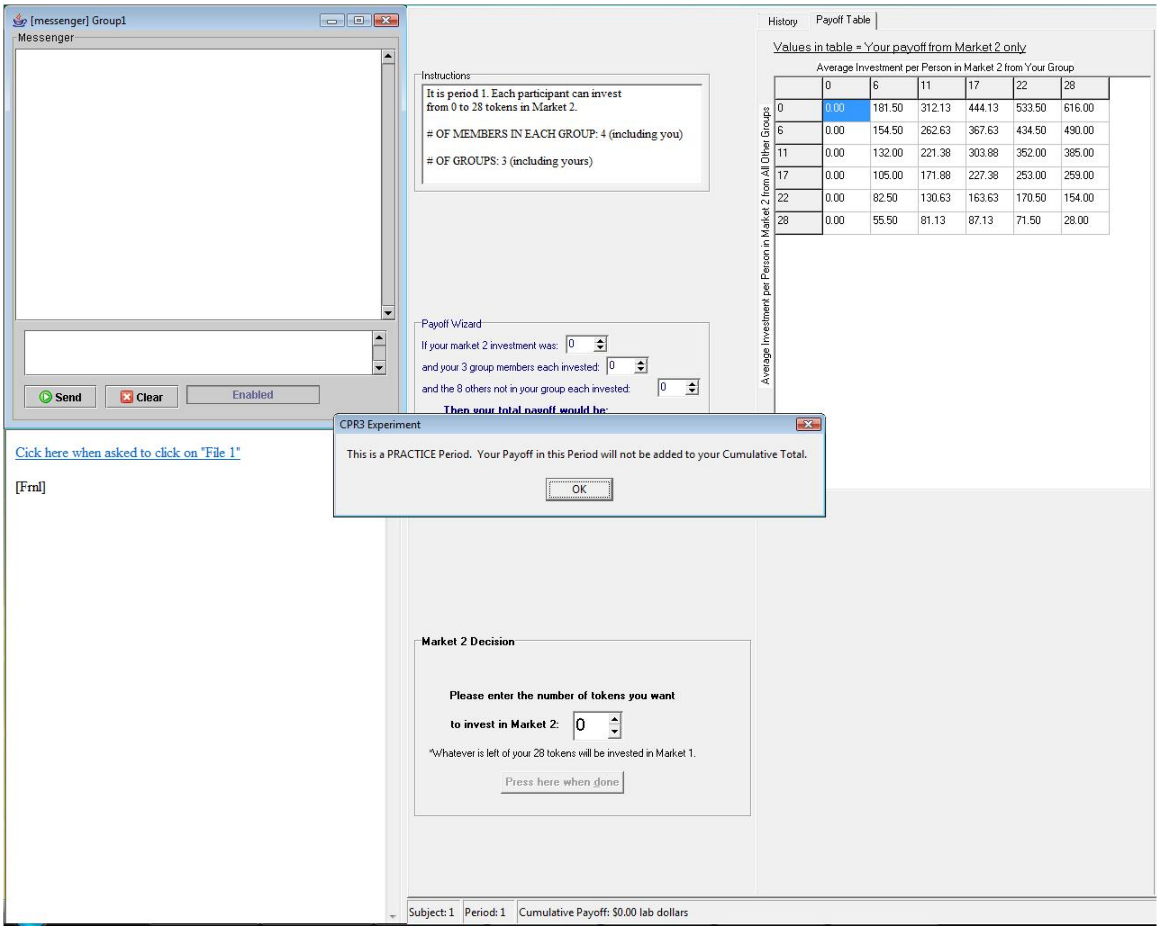

Figure III.1 Decision Screen

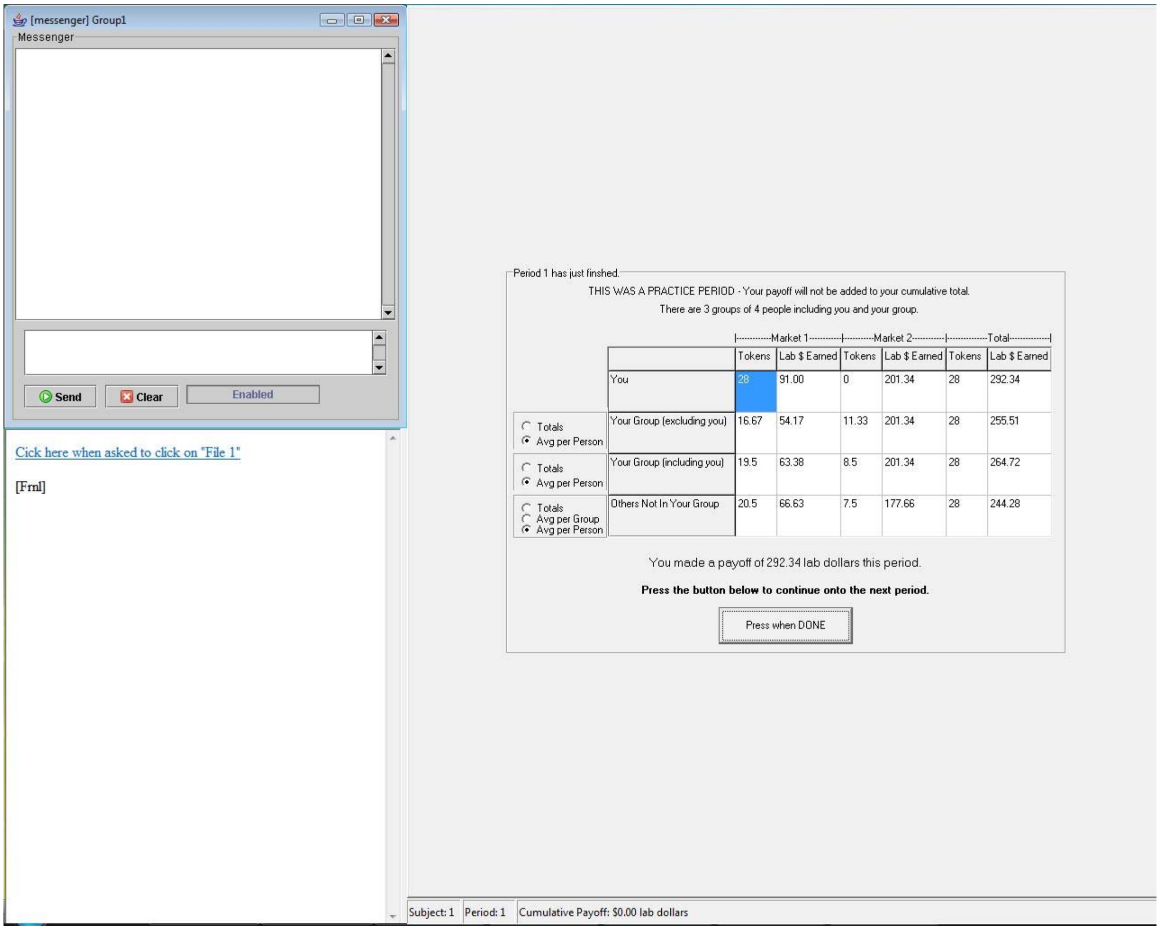

Figure III.2 Outcome Screen