Output Sharing Among Groups Exploiting Common Pool Resources

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Abstract

This paper provides an experimental testing ground for an equal output-sharing partnership approach as a common pool resource (CPR) management instrument. It examines the behaviour of resource users in output-sharing partnerships of different sizes, and evaluates the impact of partnership size and the way partners are assigned on effort (extraction) levels. Experimental results are very close to Nash predictions, and confirm that group size significantly affects resource user's effort supply. The first best solution is achieved, when resource users are privately extracting from the CPR and equally sharing their output with the socially optimal number of partners. The way partners are allocated (randomly or with the same partners over 15 periods) does not significantly affect aggregate effort contributions. Income distribution, however, is more equitable with random allocation of partners than with fixed partners.

I. Introduction

The excessive extraction from common pool resources (CPR) which leads to the destruction of the commons has been called the “tragedy of the commons” (Hardin, 1968). The notion that resource users could not escape the “tragedy of the commons” has led to suggestions of top-down management and regulation. Empirical evidence shows that neither the state nor the market have been uniformly successful in enabling individuals to sustain long term, efficient and productive use of common pool resources (Ostrom, 1990, Ostrom *et al*., 1994, Berkes *et al.*, 2001). Fishery managers increasingly realize, that resource stocks are often difficult to assess properly, and require cooperation from resource users in the collection of reliable data. If resource users are not integrated into the management of these resources, insufficient information is derived and significant costs arise from the monitoring of resource users and the enforcement of management targets. A successful management regime will be widely accepted by all resource users, and will involve resource users in the management and control of resource extraction.

Voluntary collective action may be an effective, economic and sustainable way to govern a common pool resource. Some communities have established institutions or norms to effectively deal with over-extraction. The Maine lobster fishery and Japanese coastal community cooperatives (Yamamoto, 1995), which are relatively sheltered from outside appropriators, have created successful institutions for self-management. Successful voluntary management of the CPR, however, is not easily achieved, particularly if several communities or resource users with different harvest technologies share the same CPR.

The over appropriation from the commons occurs when resource users anticipate that their behaviour has no impact on the behaviour of other resource users. This can persist if several communities use the same common property resource, but all the resource users do not share the same values, norms or institutions. Economic instruments, such as individual quotas or taxes on effort or harvest have been suggested for some CPRs. Resource users are generally not in favour of taxes because they extract rent, and because they are suspicious about the determination of the tax and its effectiveness in achieving the socially optimal outcome. Individual quotas have been introduced in some commercial fisheries (for example, in Iceland and in New Zealand), but do not seem suitable for small scale inshore fisheries (which make up approximately 90% of the total world catch from fisheries). In addition, they can cause high-grading and by-catch problems (Copes, 1986).[1] Both taxes and individual quota rely on accurate knowledge and information of the resource, and the acceptance by resource users of the assessment methods.[2] Resource users often feel that they should have an input in the determination of the harvest rate.

In Japan, some communities are pooling the catch of migratory fish instead of trying to use taxes or quota (Yamamoto, 1995). Output-sharing by groups of appropriators from the CPR can lead to a reduction of the over-appropriation common to these environments (Schott, 2002). If the optimal number of groups can be determined, the optimal exploitation of the CPR can be achieved through

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[1] In order to deal with by-catch, vessels often need to have quotas for every species they catch, which could become a complicated trading scheme. On-boat observers are required to monitor high-grading (the discarding of lower quality resources). In order to ensure efficiency, individual quotas must be geared to seasonal differences in catch rates and differences in the productivity of fishing spots.

[2] Stock assessment for the Northern cod fishery off the coast of Newfoundland and Labrador failed toward the end of the 1980s, creating political pressure and lack of confidence in scientific estimation methods.

voluntary appropriation. The logic behind output-sharing follows from the recognition that the independent voluntary appropriation from a CPR leads to over-exploitation, as appropriators fail to consider the impact that they have individually on the costs of others. By creating groups of appropriators who share the output obtained from their collective effort to appropriate from the CPR, a countervailing incentive is introduced. Having payoffs determined through the sharing of gains introduces an incentive to shirk, which leads to appropriators reducing their effort in an attempt to *free-ride* on the effort of others. The more members in the group, the greater the incentive to shirk and the greater the offset to appropriation from the CPR. The optimal sized group, given the total number of appropriators, will lead to optimal appropriation through voluntary exercise of effort.

If output-sharing groups were established for appropriation from a CPR, an obvious concern would be the effect that communication among group members will have on shirking. Laboratory results for public goods environments with communication indicate that the under-contributions which characterize environments with no communication disappear with communication (see Chan *et al.* (1999) for a good example of the effects of communication in public goods environments with homogeneous agents and heterogeneous agents). This suggests that communication among group members may offset any advantages which might be associated with the introduction of output-sharing groups for the exploitation of a CPR. A way to control for this effect, would be to randomly assign appropriators to groups so that they do not have an opportunity to enter into tacit or explicit agreements regarding appropriation.

It is important to establish that a mechanism which appears to deliver a desirable result in a theoretical environment will induce the desired behaviour from decision-makers in a controlled laboratory environment. This paper presents the experiment in a programme to evaluate output-sharing among individuals who appropriate from a CPR. Ultimately, an environment in which communication among appropriators will be considered, but in this paper communication among appropriators is not permitted. The treatments include groups of different sizes and allocations of group members in which either group members remain together over a number of rounds of appropriation from the CPR or group members are reassigned for each decision round. The former gauges the robustness of the mechanism and the latter establishes a baseline for future experiments with communication. The results indicate that group size has a significant effect on appropriation from the CPR (system effort), but that the method by which groups membership is assigned is not significant. These results suggest that output-sharing can be an effective mechanism for managing appropriation from a common pool resource if communication among appropriators is not an issue. In addition, if communication is likely and cannot be controlled, the results suggest that random allocation with output-sharing may be a successful management tool.

II. Output sharing as a CPR management instrument: Theory

Dasgupta and Heal (1979) specified a fishery model with a fixed number of harvesters, who can choose the number of vessels that they wish to employ. Each harvester, or appropriator, imposes an external cost on rivals that can be both static and dynamic in nature (Brown 1974). The former reflects the opportunity cost of congestion, while the latter reflects the scarcity value of the resource. Static externalities represent a *crowding problem*, and dynamic externalities exist if current actions lead to higher future costs. The following model focusses on the static externality problem and uses total effort applied to appropriation from the CPR as the decision variable controlled by the potential appropriators. A solution to the fundamental problem of the commons can be achieved by organizing N potential appropriators into K output-sharing partnerships (Schott, 2002). Each partnership, or group, consists of N/K = n resource users who make private decisions to allocate effort to appropriation, but who equally share output from the CPR.

In this environment, total system output is a function of the effort allocated by all individuals to appropriation from the CPR. This output function, Y = y(X), is assumed to be twice differentiable with positive first and negative second derivatives. X is the total effort allocated to appropriation from the common pool by the N individuals and Y is the resulting system output.

The profit earned by individual i in group k is

$$ {}^{k}J_{i} = w(e - {}^{k}x_{i}) + p(1/n)({}^{k}X_{g} / X)Y \qquad (1) $$

where ${}^{k}x_{i}$ is the effort from individual i in group k, w is the opportunity cost of effort put into appropriating from the CPR, e is the individual's endowment of effort, and p is the price of a unit of output from the CPR. Assume that p = 1 and that all individuals are endowed with the same amount of effort. Note that the k^{th} group receives a share of the CPR output Y equal to the relative effort it exerts, ${}^{k}X_{g} / X$, and that this output is shared equally among the n members of the group.

If we want to maximize the profit of the CPR we are interested in adding up all of the profit of all of the people appropriating from the CPR. This will result in

$$ J = wE - wX + Y \qquad (2) $$

where E is the total effort that can be devoted to appropriation by individuals. Differentiating this with respect to the effort of each of the N individuals appropriating from the CPR and setting to zero results in N equations like

$$\partial Y/\partial\, {}^{k}x_{i} = w \qquad (3)$$

$\partial Y/\partial\, {}^{k}x_{i}$ will be identical for each individual in each group. System profit will be maximized when the marginal return to a unit of effort from an appropriator is equal to the opportunity cost of allocating a unit of effort to appropriation from the CPR.

The first order condition for the maximization of profits by individual i in group k with respect to effort put into appropriation is

$$(K/N)({}^{k}X_{g} / X)(\partial Y/\partial\, {}^{k}x_{i}) + (K/N)(Y/X) - (K/N)(Y/X)({}^{k}X_{g} / X) - w = 0 \qquad (4)$$

At the margin, $\partial Y/\partial\, {}^{k}x_{i} = \partial Y/\partial\, {}^{l}x_{j}$ for all groups k and l, and all individuals i and j, therefore let $\partial Y/\partial\, {}^{l}x_{j} = \partial Y/\partial x$. Equation (4) can be solved for

$${}^{k}X_{g} = [(wNX - KY)/K][X/(X (\partial Y/\partial x) - Y)] \qquad (5)$$

There are N/K sets of conditions identical to (5) for each of the K groups. Therefore,

(i) there is not a unique value for ${}^{k}x_{i}$,

(ii) there is a unique value for ${}^{k}X_{g}$,

(iii) ${}^{k}X_{g} = {}^{l}X_{g}$ for all k, l, and therefore

(iv) ${}^{k}X_{g} = (X/K)$ for all k.

Finally, the optimal number of groups can be found. At an optimum, $\partial Y/\partial\, {}^{k}x_{i} = w$ and ${}^{k}X_{g} = (X/K)$, (4) may be rewritten as

$$w(K/N)((X/K) / X) + (K/N)(Y/X) - (K/N)(Y/X)((X/K) / X) - w = 0 \qquad (6)$$

where Y, X, and K are their optimal values. Equation (6) can be rewritten as

$$(w/N) + (K/N)(Y/X) - (Y/X)/N = w \qquad (7)$$

and then solved for the optimal number of groups

$$K = 1 + [(N-1)w/(Y/X)] \quad (8)$$

Because $w < Y/X$ when profits are maximized, $1 < K < N$. This indicates that there is an optimal output sharing group of size greater than unity but less than all of the participants who are appropriating from the CPR. If this number of equal sized groups is created, the effort voluntarily put into appropriation from the CPR will result in the maximization of the aggregated profit of the appropriators.

The next section describes a laboratory environment which captures the theoretical model presented above. Two treatment variables are considered, group size and the group allocation. Twelve participants are assigned to groups of 1, 4 or 6 individuals. The groups members are either allocated randomly at the start of the first decision-round and remain together for 15 decision rounds or they are allocated randomly at the start of the first decision-round and reallocated randomly following each decision-round. Performance measures include system effort allocated to appropriation from the CPR, individual profit, and the distribution of profit among all appropriators from the CPR. The extent to which the Nash equilibrium predictions from the model are characterized by the data is also reported.

III. Experimental design, parameterization, and predictions

The experiment consists of one treatment in which there are no output-sharing groups, and four treatments in which output-sharing is done in groups of 4 or 6 and the groups are allocated as partners (they remain together for 15 decision round) or with random assignment (after each decision round the members of the groups are reassigned). Three sessions are conducted for each of the five treatments.

This design is presented in Table 1.

[Insert Table 1]

Each session has 12 participants recruited from the general undergraduate population at McMaster University.[3] The participants received written instructions, which were read aloud to them by a monitor, prior to the start of decision-making. Participants make appropriation decisions over three practice periods before beginning the fifteen 15 decision rounds which contribute to their earnings. In the partners treatments the groups are reassigned after the three practice rounds. Appropriation decisions were made by entering a decision number through a computer keyboard. All of the information provided to participants regarding potential payoffs from their decisions and the decisions of others, and the feedback following decision rounds, were reported in a computer mediated environment (instructions are included in Appendix 1, an example of the computer screen is included in Appendix 2). Throughout a session participants had online summaries of their contributions, the average contributions of others in their groups, and the average contributions of others not in their groups. Communication among participants was not permitted (participants sat at workstations which were separated by partitions).

Participants have endowments of 28 tokens that they can invest in two markets. This is comparable to allocating effort across two activities. Market 1 yields a fixed return of 3.25 lab dollars

[3] No attempt was made to consider the sex, academic discipline, ethnicity or age of the participants as treatment variables. These nuisance variables were controlled by assigning participants to groups randomly. Participants were assigned to sessions according to their availability and the times at which they responded to our ads. Ads were posted on bulletin boards across the McMaster University campus and an ad was posted on the McMaster University Daily News website.

(L$), and represents the opportunity cost of effort. The return from Market 2 depends on the total investment in this market by all twelve participants. This represents the return from investing effort into appropriation from the CPR. The participants are told that based on the total investment made by the twelve people taking part in the session a payout per token invested is determined. This payout is in lab dollars. Each group receives a payout equal to the tokens the group invests multiplied by the per token payout from Market 2. This group payout is divided equally among the group members to determine the individual's payoff. Each token an individual does not invest in Market 2 earns a payoff of L$3.25. The average earnings for a participant in this experiment was $23.69 (median was $23.87) for approximately ninety minutes in the laboratory (the range of payoffs was $18.89 to $39.76 with a standard deviation of $2.04).

The payoff described above is the same as that presented in equation (1) where

$$Y = 32.5X - 0.09375X^2 \tag{9}$$

Given the parameters w = 3.25, e = 28, p = 1 and the output function of equation (9), the first order conditions for individual profit maximization given by equation (4) yield the Nash equilibrium predictions presented in Table 2. For these parameters, four-person groups will yield the optimal appropriation from the CPR through voluntary allocations of effort and output-sharing.

[Insert Table 2]

The theory offers no predictions with regard to the group allocations. For all hypothesis testing, the null hypothesis is that group allocation has no effect.

The effort predictions reported in Table 2 are unique system and group equilibria. Other than when the group size is unity, there are no unique *individual* equilibria for effort allocated to appropriation from the CPR. In the case of four-person groups, any combination of effort towards appropriation by a group that adds up to 52 tokens will result in a Nash equilibrium if the other two groups have each allocated 52 tokens towards appropriation from the CPR. Different allocations of effort within a group will result in different distributions of income among group members. Therefore, the non-existence of unique individual equilibria when groups of appropriators share output, makes the effect of group size on the distribution of income among appropriators from the CPR an empirical issue.

IV. Results

IV.1. System Effort

The underlying model for this experiment provides unique predictions for system effort allocated towards appropriation from the CPR for each session. While there are unique predictions for group effort allocated towards appropriations, the observations from the laboratory sessions for groups are not independent observations. Accordingly, the analysis focuses on mean per period system effort by session, mean individual payoff by session, and the standard deviation of mean individual payoff by session.

[Insert Figure 1]

Figure 1 provides a summary of the data from the fifteen sessions included in this experiment. The figure contains five time series of mean per period system effort by group size and by group allocation. When there is no output sharing (group size is unity), the predicted Nash equilibrium effort is 288. The time series in Figure 1 for this treatment appears to converge to the predicted effort over fifteen decision rounds. This is the outcome for the static CPR environment and is consistent with results reported by Ostrom, Gardner and Walker (1994) for CPR environments with eight appropriators. The result appears to be robust to increases in the number of appropriators.

With optimal effort toward appropriation of 156, too much effort is allocated. When output sharing in four-person groups is implemented, there is a noticeable reduction in the appropriation from the CPR, and this is consistent with the Nash equilibrium prediction of the model with output sharing. When output sharing in six-person groups is implemented, appropriation falls further, as predicted. The summary data in the figure suggest that group allocation does not have an effect on appropriation. The time series for groups of four are intertwined, as are those for groups of six.

[Insert Table 3]

The decision-round data presented in Figure 1 are summarized in Table 3. This table is based on fifteen independent observations on the mean per period system effort. There is one observation for each session. Increasing group size clearly results in reductions in system effort to appropriate from the CPR. The data pooled across group allocations falls from 282 to 147 to 106 tokens as group size increases from one to four to six people. There is no noticeable effect of group allocation when the data are pooled across groups that share output (125 versus 128 tokens).

Observation 1. When group size is 4 or 6, it does not matter whether the members of the groups participate as partners or are assigned to groups randomly every period.

Observation 2. The system effort exerted when group size is 4 is different than when group size is six. This difference is statistically significant.

Support: The time series presented in Figure 1 suggest that the system effort differs by group size but that group allocation does not affect system effort. Analysis of variance using the three observations on system effort for each session with multiple-person groups (12 observations in total) does not permit rejection of the hypothesis that group allocation does not matter (F test, p = 0.7462), but does permit rejection of the hypothesis that group size does not matter (F test, p = 0.0173).

Observation 3. The system effort exerted when group size is unity is greater than when group size is four or six. This difference is statistically significant.

Support: The time series presented in Figure 1 dramatically shows the difference between the system effort when there are one-person groups relative to that from multiple-person group. Randomization tests for the difference between the means reported in the Group Totals column in Table 1 yield p-values of 0.0119 when comparing system effort with one-person groups to system effort with either four-person or six-person groups.

IV.2. Nash Predictions of System Effort

Figure 1 suggests that over the fifteen periods the system effort from each treatment converges to (or close to) the predicted Nash equilibria. After fifteen periods, system effort with one-person groups is close to, but above, the Nash equilibrium effort, system effort with four-person groups is close to, but below, the Nash equilibrium effort, while system effort with six-person groups cycles around the Nash equilibrium effort in later periods.

[Insert Table 4]

Table 4 is derived from the data in Table 3 and the predictions in Table 2. This table reports the mean per period deviation of system effort from the predicted Nash equilibrium system effort by group size and group allocation. It is based on mean session data, and so convergence patterns are not reflected in this table. The same summary data are presented graphically in Figure 2.

[Insert Figure 2]

Observation 4. Although the aggregated time series data in Figure 1 suggest convergence to predicted Nash equilibrium values for system effort, it is not possible to find unambiguous statistical support for this result.

Support: An OLS regression is run using the data summarized in Table 4. The dependent variable is the deviation of mean period system effort from the Nash equilibrium prediction, and the independent variables are dummy variables for group size of 4 and group size of six, a dummy variable for random allocation of participants into groups, and an interaction between group size of 4 and the random-allocation dummy. The results of this regression are reported in Table 5.

[Insert Table 5]

Based on this OLS regression, the deviations of system effort from the Nash equilibrium predictions for one-person groups, four-person partnered groups, four-person random groups and six-person partnered groups are not significantly different from zero (F tests, $p = 0.430$, $p = 0.444$, $p = 0.113$ and $p = 0.257$ respectively). Only six-person groups allocated randomly each period do not exhibit system effort consistent with the Nash equilibrium prediction (F test, $p = 0.016$).

Because of the small number of observations (15) used in this regression, the tests of the null hypotheses that there is no difference between the observed and predicted system effort by treatment are not very powerful. A generalized estimating equations (GEE) regression permits us to use all of the system effort observations generated over the 15 periods of each of the 15 sessions and account for the session-specific variation across the 15 periods in each session.[4] This is equivalent to a random effects model. The regression coefficients using the GEE technique are identical to the OLS regression coefficients, but the semi-robust standard errors are different from the OLS standard errors. Because the error terms may be correlated within each session, STATA's robust estimation technique is used to estimate the variance-covariance matrix. This tends to lead to smaller standard errors on the coefficients, and more powerful tests. The actual forms of the tests are the same in both the OLS and GEE regressions.

Hypothesis tests from the GEE estimation for each of the five treatments indicate that only the deviation of system effort from the Nash equilibrium prediction for four-person partnered groups is convincingly not significantly different from zero (χ^2 test, p = 0.206). The data weakly support the Nash prediction for the six-person random groups (χ^2 test, p = 0.063).

Unlike the OLS regressions, which support the Nash prediction for four of five treatments, the more powerful GEE regressions support the Nash prediction in, at most, two of five treatments.[5]

IV.3. Payoffs to Participants in the CPR

In addition to knowing whether or not output sharing provides the appropriate incentives to correct the over-appropriation which characterizes an unregulated CPR, it is also important to know how the returns to the participants in output-sharing groups are affected. Adverse equity considerations

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[4] The dependent variable in the GEE regression is the difference between the system effort in each period of each session and the predicted system effort. With the GEE regression there are 225 observations, rather than the fifteen observations with the OLS regression.

[5] These results do not change if data from only the last six periods are used in an attempt to capture the intertemporal convergence shown by the data in Figure 1.

could doom an economically efficient mechanism when the politics of implementation are considered. For the environment studied here, theory provides no guide to the effects output sharing will have on income distribution, although there are clear predictions on the effect on income itself (see the rightmost column of Table 2).

[Insert Figure 3]

Figure 3 displays the distributions of session payoffs for individual participants by group size pooled across group allocation. Because there are 36 observations in the one-person groups and 72 observations in the four-person and six-person groups (36 with partners and 36 with random allocation), the distributions report the proportion of the individuals in the group which have a payoff in a particular range. The ranges are in increments of thousands of lab dollars. For example, an observation at L$3500 reports the proportion of all individuals with a particular group size that is in the range L$3500 through L$3599. Notice that there is no overlap between the distribution of payoffs to people in one-person groups (the conventional CPR environment) and the distributions to people in four-person or six-person groups.

[Insert Table 6]

Table 6 reports the mean individual payoff per session by group size and group allocation. This table is comparable to Table 3 which reports system effort. The number reported in the second row and the second column in Table 6 is the mean of three observations. Each observation is the mean session payoff of all individuals in one session in which the group size is four and the participants interact as partners. The row totals show payoffs increasing with the introduction of output sharing. Payoffs with the theoretically optimal group size of four exceed those with group size of six. For output-sharing groups, group allocation (partners or random) does not appear to have a substantial effect on payoffs.

Observation 5. When group size is 4 or 6, it does not matter to mean individual per session payoffs whether the members of the groups participate as partners or are assigned to groups randomly every period.

Observation 6. The mean individual per session payoff when group size is 4 is different than when group size is 6. This difference is statistically significant.

Support: Analysis of variance using the three observations on mean individual per session payoff for each treatment with multiple-person groups (12 observations in total) does not permit rejection of the hypothesis that group allocation does not matter (F test, $p = 0.5640$) but does permit rejection of the hypothesis that group size does not matter (F test, $p = 0.0011$).

Observation 7. The mean individual session payoff earned when group size is 1 is less than when group size is 4 or 6. This difference is statistically significant.

Support: From Figure 3, the distribution of payoffs earned by individuals when group size is 1 is totally outside of the distributions of payoffs earned by individuals in groups of size 4 and size 6. Randomization tests for the difference between the means reported in the Group Totals column in Table 6 yield p-values of 0.0119 when mean individual session payoffs for one-person groups are compared to mean individual session payoffs for either four-person or six-person groups.

These results are not surprising. They reflect the results for system effort described earlier. The results of particular interest, however, are those which reflect the effects on the distribution of income within groups. The distribution of income is measured here by the standard deviation of the payoffs to individuals in each session given group size and group allocation. The summary statistics are reported in

Table 7.

[Insert Table 7]

The number reported in the second row and the second column in Table 7 is the mean of three observations. Each observation is the standard deviation of session payoffs for all individuals in one session in which the group size is four and the participants interact as partners. The row totals shows the distribution of payoffs flattening with the introduction of output sharing. The distributions with the theoretically optimal group size of four are more disperse than those with group size of six. For output-sharing groups, group allocation has a substantial effect on the distribution of payoffs.

An analysis of variance of the standard deviations of individual payoffs by session from the twelve sessions with output sharing permits the following observations:

Observation 8. With output sharing, payoffs of members of partnered groups tend to be more inequitably distributed than payoffs of members in groups to which individuals are randomly assigned period after period.

Support: The mean standard deviation of session payoffs in partnered groups is 286 tokens and that for randomly assigned groups is 179 tokens. These are significantly different (F test, p = 0.003).[6]

Observation 9. With output sharing, payoffs of members of four-person groups tend to be more inequitably distributed than payoffs of members of six-person groups.

Support: The mean standard deviation of session payoffs in four-person groups is 267 tokens and that for six-person groups is 198 tokens. These are significantly different (F test, p = 0.029).

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[6] This difference does not disappear when the standard deviations are normalized by dividing them through by the mean individual payoff by treatment.

An OLS regression comparable to the regression reported in Table 5 permits a comparison of the dispersion between the conventional CPR environment, with no output sharing, and the sessions with output sharing. The dependent variable in this regression is the standard deviation of individual payoffs by session. The coefficients for this regression are reported in Table 8.

Observation 10. While payoffs are more equitably distributed within one-person groups than within output sharing groups (143 versus 233 respectively), the differences are most pronounced between one-person groups and partnered groups and one-person groups and four-person groups.

Support: The mean standard deviation of session payoffs in one-person groups is 143 tokens and those for the partnered groups and four-person groups are 286 and 267 tokens respectively These are significantly different (F tests, p = 0.002 and p = 0.004 respectively). The differences between the mean standard deviations of session payoffs in one-person groups and those for randomly assigned groups and six-person groups are not significantly different (F tests, p = 0.302 and p = 0.125 respectively).

At first it may be surprising that payoffs are more inequitably distributed in the partnered groups than in the randomly allocated groups. But recall that when you are in a partnered group, you can behave strategically. There is not a unique individual Nash equilibrium for participants in output-sharing groups. If you can get others in your group to increase their effort, while you reduce yours, you can increase your payoffs. This incentive to behave strategically in order to benefit from your partners' increased appropriation does not exist in the environments with one-person groups or with multi-person groups in which individuals are randomly assigned. This shows up in the data. The standard deviations of individual payoffs by session in randomly assigned groups are lower than in partnered groups, regardless of group size.

V. Summary and Discussion

The objective of this experiment was to evaluate the incentives induced by introducing a countervailing externality as an mechanism for correcting the misallocation resulting from the congestion externality common to CPR environments. The theoretical development of this approach predicts that increasing the size of the group within which output-sharing is imposed will lead to lower system effort. This means a reduction in over-appropriation. There is an optimal group size, for which the congestion externality is precisely offset by the shirking externality introduced by output sharing. If a regulator could discover this optimal group size for a CPR that is being over-exploited, the imposition of output-sharing would lead to efficient exploitation of the CPR.

The induced incentives were evaluated in a laboratory environment, comparable to a CPR environment, in which human participants made appropriation decisions. Group size and the characteristics of the group allocation were varied across sessions in a two-by-two factorial design which created four treatments. A fifth treatment, the baseline CPR environment was also created. In this treatment there was no output sharing.

The results of fifteen laboratory sessions, involving 180 participants, strongly support the theoretical prediction that introducing output sharing will reduce appropriations from the CPR and that increasing group size will reduce appropriations. Although the data appear to be organized well by the Nash equilibrium predictions from the theoretical model, given the parameters used in the laboratory environment, there is not unambiguous support for the data supporting the Nash equilibrium predictions.

The Nash equilibrium prediction for the partnered four-person groups (the optimal group size) is, however, supported by the data. Whether participants are in output-sharing groups whose membership changes before each decision round or are in groups whose membership is constant over fifteen decision rounds has no significant effect on appropriation.

The data show that introducing output-sharing increases individual payoffs and results in greater mean payoffs with four-person groups than with six-person groups. This is consistent with the theory. What the theory provides no guidance for is how the distribution of income will be affected by the introduction of output sharing. In the baseline CPR environment the distribution of payoffs, as measured by the standard deviation of payoffs to all participants in the CPR, becomes less equitable with the introduction of output sharing. Given output sharing, payoff distributions become less equitable as we move closer to the optimal group size. Group allocation is not immune to a distribution effect. When group membership is reassigned randomly each period, income distribution is more equitable than when group membership is unchanged period after period. This latter result may be consistent with strategic behaviour in partnered groups which cannot be conducted effectively in groups whose members are randomly reassigned each decision round.

Recognizing that output sharing does induce the appropriation behaviour that the theory predicts makes output sharing worth considering as a management instrument. Its imposition does require acceptance by the people who will be regulated. The promise of increased payoffs may help implementation, in spite of the potentially increased dispersion of payoffs. While the use of output sharing may be an effective tool for managing a CPR if participants are unable to communicate, the impact of communication has not yet been evaluated.

Consider a CPR such as an inshore fishery.[7] The people appropriating from the fishery live in several communities along the coastline that defines this fishery (imagine a large bay which defines the fishery and villages scattered along the coastline). With partnered groups, output sharing could be implemented by identifying groups as sets of coastal communities. With random groups, output sharing could be implemented by randomly assigning people to groups and then reassigning them to groups at the start of each "appropriation" period. Using the parameters introduced in this paper, Table 9 shows the equilibrium predictions for effort from Table 2 along with the equilibrium predictions associated with an environment in which the people *within* output-sharing groups make collective appropriation decisions which they can enforce. The effect of this communication and collective decision-making is to reduce the countervailing shirking externality that made output sharing work so well in the absence of communication.

[Insert Table 9]

Think of the twelve participants in this CPR environment as representing six communities with two people in each community. A four-person output-sharing group would consist of a pair of communities. A six-person output-sharing group would consist of a trio of communities. As an example, consider the case of four-person groups. These could be output-sharing groups, who are able to communicate among themselves, or these could be communication groups. In the former case, if they can enforce a group optimal appropriation of effort through communication, the prediction in

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[7] This is not an open access environment. The only people using the inshore fishery, if it is a common pool resource, are members of a well defined set of individuals. To them, this resource is a common pool of fish.

Table 9 may characterize this environment. This would not be a strong endorsement of output sharing. In the latter case the output-sharing groups would be randomly assigned at the start of each "appropriation" period, but the communication groups remain constant. Our theory does not help us predict how communication among these groups will affect appropriation. If this sort of communication does not reduce shirking, then it may be possible to implement output sharing in the presence of communication and successfully increase payoffs to appropriators from the CPR. There is evidence in Kinukawa *et al.* (2000), within the context of a voluntary contribution game, that this sort of *partial* communication will not reduce shirking.

While the theory that pits shirking against over-appropriation behaviour as a regulatory instrument is intriguing, it is necessary to identify the extent to which its predictions will be reflected by individual behaviour. Aspects of the naturally occurring environment, such as communication among participants, are difficult to capture with the theory, but can be implemented in controlled laboratory settings. This is the direction in which research on output sharing as a regulatory mechanism should go.

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Table 1. Experimental Design: Number of Sessions by Group Allocation and Group Size

Group Size	Group Allocation		
	No Output Sharing	Output Sharing: Partners	Output Sharing: Random Assignment
One-Person Groups	3		
Four-Person Groups		3	3
Six-Person Groups		3	3

Table 2. Nash Equilibrium Predictions for System Effort per Period, Group Effort per Period, and Mean Individual Session Payoff by Group Size

	System Effort per Period (Tokens Appropriated)*	Group Effort per Period (Tokens Appropriated)*	Mean Individual Session Payoff in Lab Dollars
One-Person Groups	288	24	2175
Four-Person Groups	156	52	4216.88
Six-Person Groups	92	46	3736.7

* The maximum number of tokens that can be appropriated in any period is 28 for an individual and 336 for the system. System aggregate payoff is maximized when 156 tokens are appropriated.

Table 3. Per Period System Effort by Group Size and Group Allocation based on Session Data (standard deviations are in parentheses)*

	Group Allocation			
Group Size	No Output Sharing	Output Sharing: Partners	Output Sharing: Random Assignment	Row Totals
One-Person Groups	282.24 (3.59)			282.24 (3.59)
Four-Person Groups		150.42 (9.04)	143.82 (11.69)	147.12 (10.02)
Six-Person Groups		100.42 (2.93)	112.22 (22.27)	106.32 (15.60)
Column Totals	282.24 (3.59)	125.42 (28.04)	128.02 (23.51)	157.83 (68.03)

* There are three sessions for each treatment.

Table 4. Mean per Period Deviation of System Effort from the Predicted Nash Equilibrium System Effort by Group Size and Group Allocation based on Session Data (standard deviations are in parentheses)*

	Group Allocation			
Group Size	No Output Sharing	Output Sharing: Partners	Output Sharing: Random Assignment	Row Totals
One-Person Groups	-5.76 (3.59)			-5.76 (3.59)
Four-Person Groups		-5.58 (9.04)	-12.18 (11.69)	-8.88 (10.02)
Six-Person Groups		8.42 (2.93)	20.22 (22.27)	14.32 (15.60)
Column Totals	-5.76 (3.59)	1.42 (9.74)	4.02 (23.83)	1.03 (15.88)

* There are three sessions for each treatment.

Table 5. OLS Regression Coefficients to Test for Nash Equilibria in the System Effort Data (Dependent Variable is the Mean per Period Deviation of System Effort from the Predicted Nash Equilibrium System Effort)

Independent Variable	Coefficient	Standard Error	p-Value
Constant (Group Size One)	-5.755	7.002	0.43
Group Size 4	0.178	9.902	0.986
Group Size 6	14.178	9.902	0.183
Random Allocation	11.8	0.902	0.261
Group Size 4 and Random	-18.4	14.004	0.218
Observations = 15	$R^2 = 0.584$	Adjusted $R^2 = 0.417$	$F(4, 10) = 3.50$ $p = 0.049$

Table 6. Mean Individual Payoff per Session by Group Size and Group Allocation (standard deviations of the session means are in parentheses)*

Group Size	Group Allocation: No Output Sharing	Output Sharing: Partners	Output Sharing: Random Assignment	Row Totals
One-Person Groups	2304.49 (103.93)			2304.49 (103.93)
Four-Person Groups		4170.40 (24.80)	4152.03 (39.83)	4161.21 (31.34)
Six-Person Groups		3814.99 (54.14)	3906.32 (197.45)	3860.66 (138.82)
Column Totals	2304.49 (103.93)	3992.70 (198.28)	4029.18 (185.31)	3669.65 (726.17)

* There are three sessions for each treatment.

Table 7. Mean Standard Deviation of Individual Payoffs per Session by Group Size and Group Allocation (standard deviations of the session standard deviations are in parentheses)*

	Group Allocation			
Group Size	No Output Sharing	Output Sharing: Partners	Output Sharing: Random Assignment	Row Totals
One-Person Groups	143.49 (56.51)			143.49 (56.51)
Four-Person Groups		318.36 (5.08)	215.36 (47.33)	266.86 (63.94)
Six-Person Groups		253.86 (70.83)	143.07 (17.56)	198.46 (76.24)
Column Totals	143.49 (56.51)	286.17 (57.21)	179.22 (50.87)	214.83 (79.73)

* There are three sessions for each treatment.

Table 8. OLS Regression Coefficients to Test for Effects on Payoff Distributions by Group Size and Group Allocation (Dependent Variable is the Standard Deviation of Individual Payoffs per Session)

Independent Variable	Coefficient	Standard Error	p-Value
Constant (Group Size One)	143.49	26.81	0
Group Size 4	174.86	37.92	0.001
Group Size 6	110.36	37.92	0.016
Random Allocation	-110.79	37.92	0.015
Group Size 4 and Random	7.79	53.63	0.887
Observations = 15	R^2 = 0.758	Adjusted R^2 = 0.661	F(4, 10) = 7.82 p = 0.004

Table 9. Per Period Group and System Effort with Individual or Group Optimization

Members in Group	Group Effort with Individual Optimization	System Effort with Individual Optimization	Group Effort with Group Optimization	System Effort with Group Optimization
1	24	288	24	288
4	52	156	78	234
6	46	92	104	208

Note: All of these values are Nash equilibria for the particular group sizes and optimization contexts. The allocation of effort that will maximize system profits occurs when the system effort is 156.

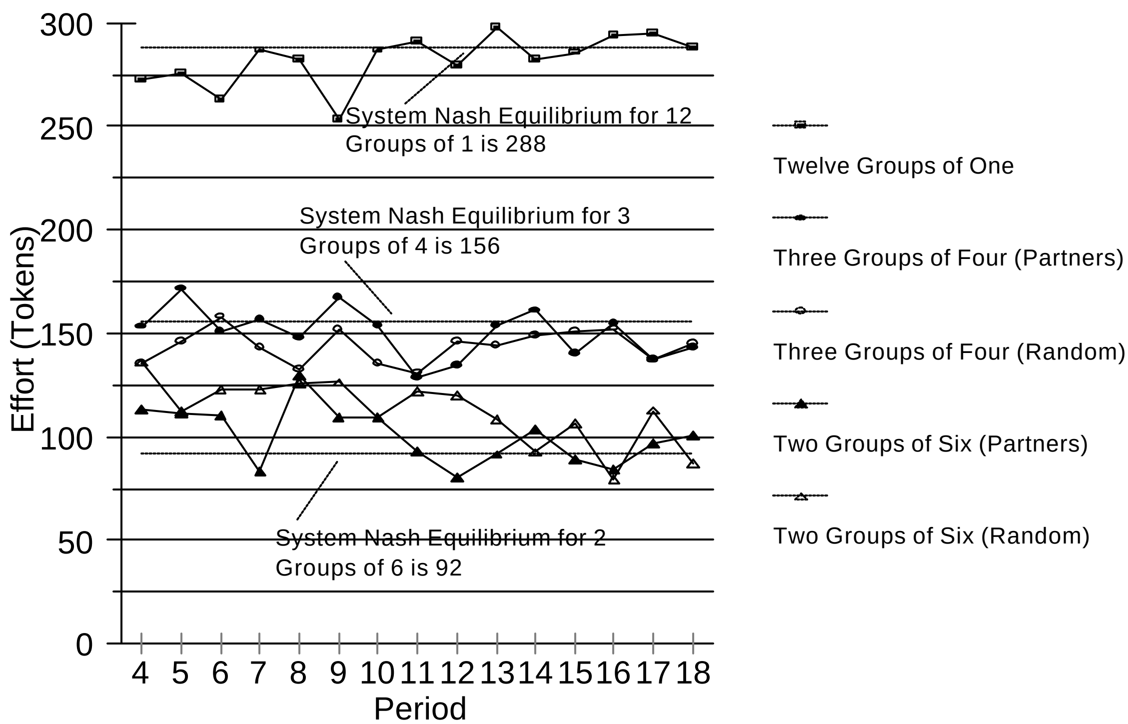


Figure 1. Mean System Effort by Group Size and Group Allocation

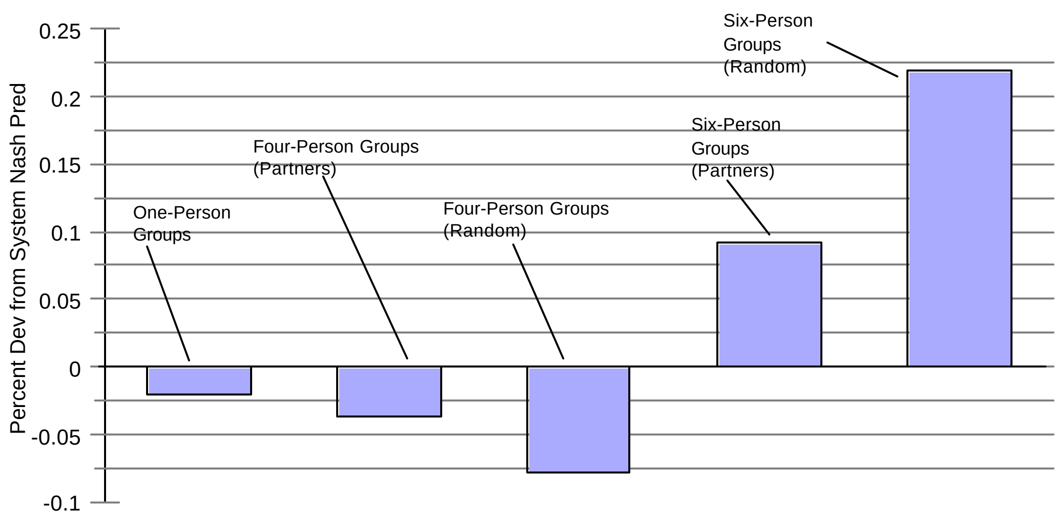


Figure 2. Mean per Period Percentage Deviation of System Effort from the Predicted Nash Equilibrium System Effort by Group Size and Group Allocation based on Session Data

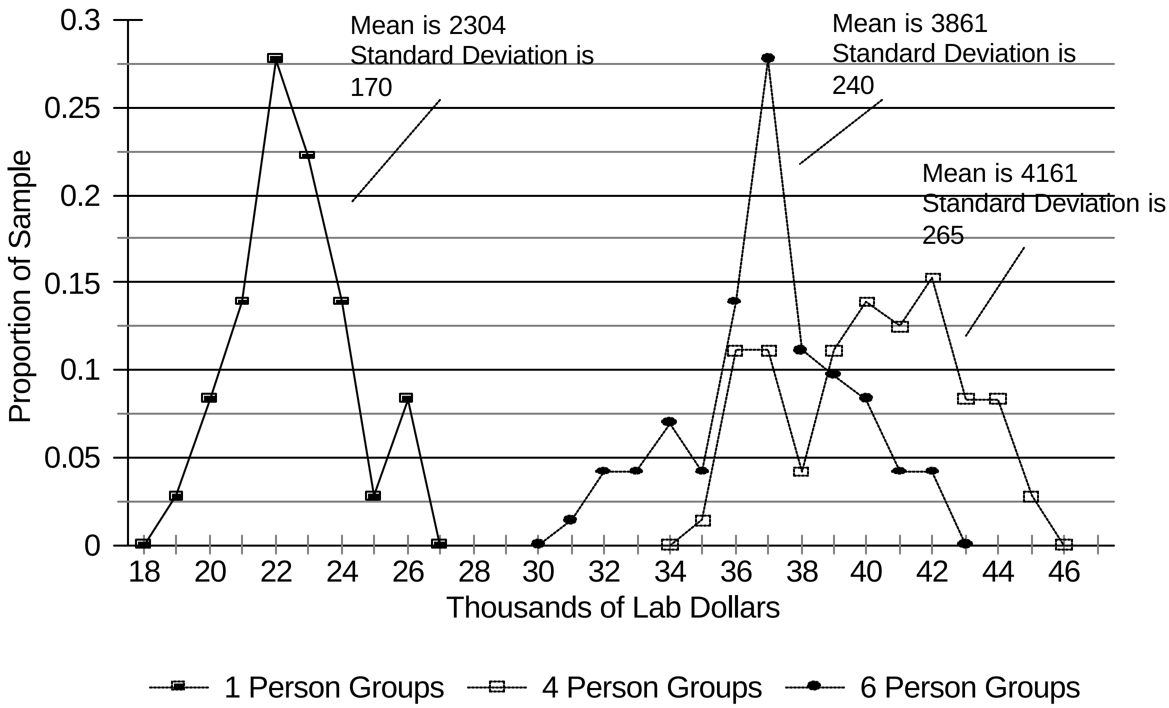


Figure 3. Distributions of Individual Session Payoffs by Group Size

APPENDIX 1: INSTRUCTIONS (GROUPS OF 4 PARTNERS)

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 three 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 the three 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. . 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 0.005×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 three groups of four 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:

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

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

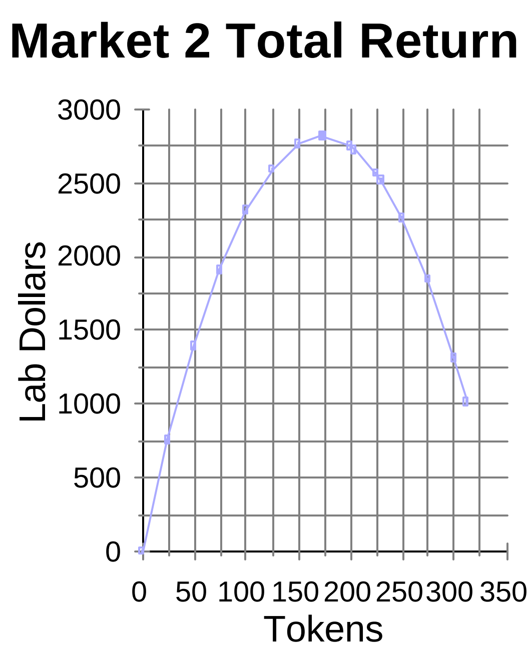
3. The total investment in Market 2 by the participants not in your group is 8×17 = 136 tokens.

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

5. 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$13.37.

Market 2 Total Return Table

Tokens	Total Return	Average Return per Token
0	0	0
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	13.75
204	2728.5	13.375
225	2566.41	11.406
250	2265.63	9.063
275	1847.66	6.719
300	1312.5	4.375
325	660.16	2.031
336	336	1



6. 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.

7. 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.

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

9. 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	181.5	312.13	444.13	533.5	616
	6	0	154.5	262.63	367.63	434.5	490
	11	0	132	221.38	303.88	352	385
	17	0	105	171.88	**227.38**	253	259
	22	0	82.5	130.63	163.63	170.5	154
	28	0	55.5	81.13	87.13	71.5	28

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 groups 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 **three practice periods.** The results from these periods will **not** contribute to your final earnings. If you have any questions during these three periods, please raise your hand and we will answer them.

After the three 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 Two 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 three is 68 tokens; divided by 4 equals 17 tokens). Under these hypothetical conditions, your payoff from Market Two 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. For example, suppose the others in your group lower their average investment in Market 2 to 11 tokens. Please change the value in the spin-edit box for the others in your group to 11. Notice that your payoff in Market 2 falls to L$171.88 and your total payoff falls to L$227.13.

Now try changing your assumed investment in Market 2. Suppose you lower your investment in Market 2 from 11 to 6. Note that your total payoff rises to L$228.41. Suppose that the average

investment in Market 2 by all participants other than those in your group falls to 14. Note that your total payoff rises to L$250.35. Now change your investment in Market 2 to 15 tokens. Notice that your total payoff now rises to L$252.25.
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. 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)

Paid Periods

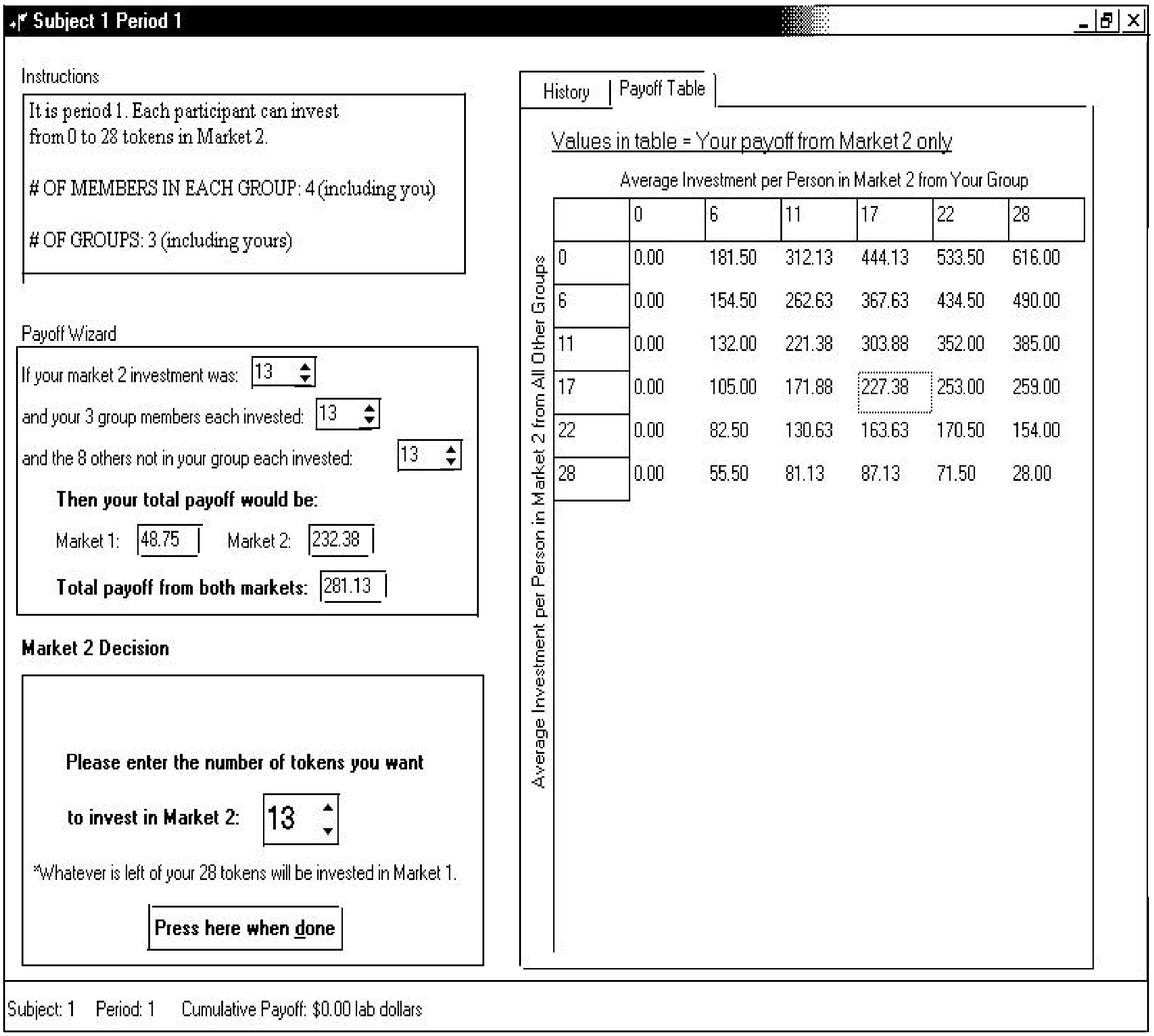
We are now about to begin the paid portion of the session. At the beginning of the next period we will scramble the membership of all the groups so that your group will consist of a completely new set of four people. You will remain grouped with this new set of participants for the next 15 periods.

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.

APPENDIX 2: PARTICIPANT'S SCREEN

For an explanation of how this screen is used during the decision round of a laboratory session, please refer to the Instructions in Appendix 1. This screen corresponds to the treatment with groups of 4 participants who are partnered throughout the fifteen decision rounds of the session.



	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