Output Sharing Among Groups Exploiting Common Pool Resources

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Key words: Common pool resources, experimental economics, natural resource management
JEL classification codes: Q20, C91, C92

Draft
March 1, 2004
Please contact authors before citing.

Abstract

Equally sharing the harvest from a common pool resource (CPR) introduces a free-riding incentive which may offset the over-harvesting incentive of the CPR. We conduct a laboratory experiment to assess the performance of output sharing by introducing equal-sharing groups of size one, four and six into a twelve-person CPR environment. Assignment to groups is varied at two levels (strangers or partners). Group size significantly affects effort. Aggregate effort levels are not significantly different from Nash predictions. The firs 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. Income distribution, however, is more equitable with random allocation of partners than with fixed partners.

I. Introduction

Economists have suggested to use two policy instruments to control for the excessive extraction from common pool resources (CPR): individual quotas (IQs) or individually transferable quotas (ITQs) and Pigouvian taxes. Quantity-based instruments such as ITQs have surprisingly received more attention in policy applications. Recent theoretical and empirical evidence has indicated several problems with ITQs and other quantity-based instruments in CPR extraction, particularly in the world s fisheries. Parcival Copes (1986) warnings about by-catch, high-grading and other negative side effects of quota management were confirmed by on-board vessel inspections and declining fish populations and harvests reports in many fisheries over the last 20 years (Parsons, 1993, The Economist, 2003). Tom Tietenberg (2000) pointed out that permit or individual quotas seem to work much better with pollution markets than for common property resources. A recent OECD (1997) review of 37 IQ and ITQ fisheries found that two thirds of them experienced at least temporary declines in stocks after instituting the programs. The OECD study stated inadequate information about resource stocks on which to set conservative total allowable catches (TACs) and illegal fishing activity as reasons for not sustaining stocks and harvests. The latter two reasons and the concern about by-catch and high-grading motivated an increasing search for alternatives to IQs and ITQs. Weitzman (2002) shows that harvest taxes or landing fees are superior to IQs and ITQs under environmental uncertainty and resource stock fluctuations. Price-based instruments set better marginal incentives and provide important feedback to resource managers. Quota management only works well if resource managers can predict resource stocks very precisely and accurately. Feedback usually is not very valuable because harvesters merely report catches that conform with allocated shares. Taxes, on the other hand, provide resource managers with information on how harvesters react to incentives, and harvest data is more useful as it can help to update stock assessments and management targets.

Harvest taxes, however, do not necessarily avoid the other two major problems identified earlier. A harvest catch does not avoid high-grading behaviour or by-catch unless different grades of fish (e.g. age classes, qualities, species) are charged different taxes which could be tedious and administratively difficult. It is also not likely that it will get rid of cheating and illegal harvesting activities. Harvesters have not been supportive of instruments that extract rents and might, therefore, might react by increasing illegal activities (see Bell et al., 1989 for a tradeoff between cheating and economic sanctions). Resource users could also easily become suspicious about the underlying reasons for setting and changing tax rates.

Many CPRs have been used successfully without intervention because community members obeyed social rules, created institutions for local self-government, or voluntarily restricted effort (e.g. Ostrom, 1990, Ostrom *et al.*, 1994, Pinkerton, 1994, Yamamoto, 1995, Sethi and Somanathan, 1996, Berkes *et al.*, 2001). Voluntary collective action may be an effective, economic and sustainable way to govern a common property resource. It avoids a separation of ownership, management and resource use between harvesters and a regulator, that often leads to mistrust between both sides, and undesired side effects (such as discarding, cheating, misreporting, etc.). Successful self-management of resources, however, requires face-to-face communication or appropriate institutional arrangements as was shown in laboratory experiments by Hackett *et al.* (1994), Ostrom *et al.* (1994) and Walker *et al.* (2000). When several communities or social groups exploit the same CPR, sufficient communication links might exist within each social group but not among the different groups, and, therefore, partial communication alone would not necessarily lead to the socially efficient use of the CPR (Kinukawa *et al*., 2000).

With many large-scale migratory resources we cannot exclusively rely on voluntary cooperation of resource users; however, this does not imply that we should instead switch to top-down management and ignore the rules and institutions harvesters adhere to. When voluntary collective action is not sufficient to avoid resource degradation or increase the efficiency of extraction, other innovative approaches are necessary to guarantee efficient sharing and extraction of the resources that are accepted by the majority of resource users. Both individual quotas and harvest taxes do not seems to be the right instruments to solve commons dilemmas in many situations, particularly in the fishery.

An interesting parallel to the CPR problem occurs in the theory of the labour managed firm. Sen (1966) pointed out that members of a labour managed firm will work too hard (at an inefficient level of effort) if they receive a share of the firm s output according to their relative labour input. Equal output-sharing, on the other hand, would lead to underprovision of effort because members will free-ride on the efforts of others. Sen proposed a sharing rule such that a proportion of labour remuneration depends on relative labour input and the remaining portion is an equal share of profit independent of their actual contribution. An important feature of this model is the need to monitor relative labour input, a potentially costly activity.

Schott (2003) uses insights from Sen s paper to derive a non-cooperative output-sharing approach to CPR management. Under open access conditions in CPRs, harvesters are remunerated according to their relative level of effort, as measured by their individual appropriation. This creates the standard overharvesting incentive in a common pool. The challenge is to find an offsetting incentive, such as the equal output-sharing rule analysed by Sen, which will restrict effort to the optimal level. Schott (2003) builds on this idea to suggest an approach for optimal CPR management. He proposes dividing resource users into an optimal number of independent partnerships (the Nash equilibrium in his model depends on the number (or size) of partnerships). Within each partnership the harvest is shared equally. Provided members of each partnership act non-cooperatively, this creates a strong incentive to reduce effort. As opposed to taxes or auctioned IQs, revenues remain with resource users, and the potential misuse of policy instruments to raise revenue or improve political prospects is eliminated or reduced. Output-sharing also does not have negative side effects, such as high-grading or by-catch as experienced with IQ or ITQ management. It could furthermore facilitate cooperation between different social groups exploiting the same CPR by linking a resource user s payoff to the decisions of resource users from different groups or communities.

The possibility of applications of the output-sharing partnership mechanism goes beyond the CPR environment. The parallel established to the labour-managed firm literature by Schott(2003) demonstrated the similarity of CPR problems and other social dilemmas where rivalry and free-riding coexist. A variant of output-sharing is used in many firms in the form of profit-sharing or stock options as a substitute for salaries, for example. Law firms often share profits equally with their partners (Farrell and Scotchmer, 1988). Whenever it is costly to monitor and enforce the input of effort or contributions to a public good, it is convenient to rely on equal output-sharing. Free-riding could be overcome by partitioning parties into independent partnerships. Smaller group sizes have the effect of off-setting some of the free-riding incentives, which allows groups of any sort to efficiently balance excessive rivalry and shirking.

Schott (2003) points out that his results change if there is explicit or implicit collusion among resource users. In his formal model he randomly assigns harvesters to groups and analyses a static model (albeit with conjectural variations). In the field, however, this condition may not be met unless elaborate precaution is taken in the sharing of the resource. Schott's (2003) plan also has implications for the distribution of earnings among resource users. Because output is shared equally within groups, there is no unique Nash equilibrium individual contribution, which could allow a wide variation in individual payoffs, even when group effort is optimally chosen. This raises concerns about the fairness and stability of the system.

This paper reports and discusses results of an experiment designed to test three aspects of output-sharing in a laboratory environment. First it tests whether the predictions of the theory are borne out in the lab. Specifically it test whether the size of the output-sharing group affects the aggregate level of extraction as predicted by the theory. Secondly, it investigates whether behaviour is sensitive to the group allocation rule. We contrast a "partners" treatment in which group membership is held constant with a "stranger" treatment in which group membership is rotated randomly each period. Experimental evidence from linear public goods models is inconclusive about the size and direction of the stranger/partner effect (Andreoni, 1988, Croson, 1996, Andreoni and Croson, 2002). We believe it is important to study the contrast in the CPR environment both because the CPR environment is nonlinear in contribution and because the results may have strong implications for the field implementation of this institution. Finally the paper investigates the effect of group allocation rule and group size on the dispersion of individual incomes. This is important because the political feasibility of the plan would probably be affected by perceived fairness of the instrument.

The results indicate that group size has a significant effect on appropriation from the CPR, but that the method by which group membership is assigned is not significant for mean appropriation levels. This suggests that output-sharing can be an effective mechanism for managing appropriation from a common pool resource if explicit communication among appropriators is not an issue. In addition, if explicit communication is likely and cannot be controlled, random allocation with output-sharing could be a successful management tool. Income distribution with random allocation (strangers) also tends to be more equitable than with fixed partners. The differences in income distribution, however converge in the second half of experimental sessions.

II. Output sharing as a CPR management instrument: Theory

Dasgupta and Heal (1979) specified a CPR 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 socially efficient solution that maximizes aggregate profit 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 (X) allocated by all N individuals to appropriation from the CPR. The resulting system output function, Y = y(X), is assumed to be twice differentiable with positive first and negative second derivatives.

The profit earned by individual i in group k is

$$ {}^{k}\ {}_{i} = w(e - {}^{k}x_i) + p(1/n)({}^{k}X_g / X)Y \qquad (1) $$

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 kth 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

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

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

$$ Y/\ {}^{k}x_i = w. \qquad (3) $$

The term on the left hand side ($Y/\ {}^{k}x_i$) 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

$$(K/N)({}^kX_g / X)(\ \ Y/\ \ {}^kx_i) + (K/N)(Y/X) - (K/N)(Y/X)({}^kX_g / X) - w = 0 \tag{4}$$

Since all groups and individuals are identical, , $Y/\ \ {}^kx_i = \ \ Y/\ \ {}^lx_j$,and we can replace the latter by $Y/\ \ {}^lx_j = \ \ Y/\ \ x$. Equation (4) can be solved for

$${}^kX_g = [(wNX - KY)/K][X/(X(\ \ Y/\ \ x) - Y)] \tag{5}$$

There are N/K sets of conditions identical to (5) for each of the K groups. We can conclude that:

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

(ii) there is a unique value for ${}^kX_g$,

(iii) ${}^kX_g = {}^lX_g$ for all k, l, and therefore

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

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

$$w(K/N)((X/K) / X) + (K/N)(Y/X) - (K/N)(Y/X)((X/K) / X) - w = 0 \tag{6}$$

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

$$(w/N) + (K/N)(Y/X) - (Y/X)/N = w \tag{7}$$

and then solved for the optimal number of groups:

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

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 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 (*partner* treatment), or they are allocated randomly at the start of the first decision-round and reallocated randomly following each decision-round (*stranger* treatment). 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 evaluated.

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 rounds) or as *strangers* (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.[1] The participants received written instructions, which were read aloud to them by a monitor, prior to the start of decision-making. Participants then made appropriation decisions over three practice periods before beginning the 15 decision rounds which contributed to their earnings. In the partners treatments the groups were reassigned after three practice rounds and then remained in the same group for the remaining 15 decision 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.[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 had endowments of 28 tokens that they could invest in two markets. This is comparable to allocating effort across two activities. Market 1 yields a fixed return of 3.25 lab dollars (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. The latter represents the return from investing effort into appropriation from the CPR. The participants were told that the total

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[1] 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.

[2] Instructions and an example of the computer screen seen by a participant can be found at http://socserv.socsci.mcmaster.ca/~econ/mceel/papers/schottapp.pdf

investment made by the twelve participants would determine a payout per token invested in Market 2. Each group received a payout equal to the tokens the group invests multiplied by the per token payout from Market 2. The group payout was divided equally among the group members to determine the individual s payoff. Each token an individual did not invest in Market 2 earned a private 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) yields 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. The non-existence of unique individual equilibria when groups of appropriators share output, therefore, 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 summarizes 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. It is immediately evident that the results are broadly consistent with the underlying theory. 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. Increasing group size clearly reduces aggregate effort applied to the CPR. Moreover the observations for each group size lie close to the Nash equilibrium benchmarks, particularly in the later periods of each session.

[Insert Table 3]

Table 3 cross-tabulates mean system effort by group-size and group assignment. There is one observation for each session. Again, 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. It does not matter whether the members of the groups participate as partners or are assigned to groups randomly every period (as strangers).

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 groups. 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 approximates 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. Mean system effort approximates Nash equilibrium but does not converge precisely to it.

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 four and group size of six, a dummy variable for random allocation of participants into groups, and an interaction between group size of four 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.[3] This is equivalent to a random effects model. The regression coefficients using the GEE

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[3] 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.

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 (^{2} test, $p = 0.206$). The data weakly support the Nash prediction for the six-person random groups (^{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.[4]

The failure of effort to converge precisely to the Nash equilibrium benchmarks should not be given excessive weight. As noted earlier, all theories abstract from many factors affecting field and laboratory outcomes. The lack of precise convergence indicates that some of these factors are influencing the observed behaviour. The validity of the output-sharing theory is demonstrated more by its outstanding success at predicting changes in effort when group size changes.

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[4] 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.

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 or reduced average incomes 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). The individual payoff reaches a maximum at the socially efficient group size of 4.

[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 strangers), 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. Even the worst off participants in any of the output-sharing experiments had larger payoffs than the participants that had the largest payoffs in the individual appropriation experiments without output-sharing.

[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 increasing payoffs 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 strangers) 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 strangers.

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 clearly lies 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 coefficient of variation of the payoffs to individuals in each session given group size and group allocation.[5] The summary statistics are reported in Table 7.

[Insert Table 7]

The values reported in Table 7 are the means of three observations. Each observation is the coefficient of variation of session payoffs for all individuals in one session of a given treatment (for example groups size of four and partners) . The row totals show the distribution of payoffs relatively unchanged with the introduction of output sharing. The distributions with the theoretically optimal group size of four are marginally more disperse than those with group size of six. Six person groups (in aggregate) have a smaller coefficient of variation than one person

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[5] The coefficient of variation is the standard deviation of payoffs to individuals in a session divided by the mean payoff to these individuals times 100. As group size and allocation to group changes, the payoffs to appropriators from the CPR change. To compare the distributions of income across the different treatments, a measure which expresses the magnitude of the variation relative to the payoffs themselves is used. This provides a normalized measure of the distribution of payoffs in each treatment. Using the coefficient of variation as a measure of income distribution will lead to a conclusion that income distribution has become more equitable if mean income increases but the standard deviation of income does not change. Income distribution becomes less equitable only if the standard deviation of income increases (decreases) by more (less) than mean income rises (falls).

groups or output-sharing groups of four. For output-sharing groups, group allocation, however, has a substantial effect on the distribution of payoffs.

An analysis of variance of the coefficients of variation 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 (as strangers).

> **Support:** The mean coefficient of variation of session payoffs in partnered groups is 7.15 and that for randomly assigned groups is 4.43. These are significantly different (F test, p = 0.004).

Observation 9. With output sharing, the distribution of payoffs of members of four-person and six-person groups tend to be comparable.

> **Support:** The mean coefficient of variation of session payoffs in four-person groups is 6.41 and that for six-person groups is 5.17. These are not significantly different (F test, p = 0.104).[6]

> 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

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[6] If the standard deviations of session payoffs (not normalized) are used as the measure of income distribution, Observation 8 is maintained. Observation 9, however, would have to be modified. Based on standard deviations alone, there is a statistically significant group-size effect. This could lead to the conclusion that income distribution has become less equitable (following an increase in the standard deviation of payoffs) even though the range of incomes within a standard deviation of the mean income as a proportion of the mean income has fallen.

dependent variable in this regression is the coefficient of variation of individual payoffs by session. The coefficients for this regression are reported in Table 8.

Observation 10. Payoffs are comparably distributed within one-person groups and output sharing groups.

Support: The mean coefficients of variation of session payoffs in one-person groups and in output-sharing groups are 6.19 and 5.79 respectively. These are not significantly different (F tests, p = 0.680).

Although the distribution of payoffs differs between partnered and randomly assigned groups, the distribution of payoffs in one-person groups is not different from that in either of these groups. This is explained by the relatively large standard deviation of the coefficient of variation for the one-person groups and the opposite effect on income distribution associated with the allocation to groups in output-sharing environments. When groups are partnered, income distribution widens from the one-person group case, while when participants are randomly allocated to groups, income distribution narrows. The differences between partnered and randomly assigned output-sharing groups, as reported above, are significant.

V. Summary and Discussion

The objective of this experiment was to evaluate the incentives induced by introducing a countervailing externality as a 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. Under uncertainty about the resource stock and or resource users behaviour, a regulator could start with a relatively large output-sharing group and could then slowly reduce group size as long as output and average income were increasing.

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, the observations do not converge precisely to 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 (strangers) or are in groups whose membership is constant over fifteen decision rounds (partners) has no significant effect on average 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. The theory provides no guidance on how the distribution of income is affected by the introduction of output sharing. In the baseline CPR environment the distribution of payoffs, as measured by the coefficient of variation of payoffs to all participants in the CPR, is unchanged with the introduction of output sharing. With output-sharing, group size had no effect on income distribution. Group allocation, however, is not immune to a distribution effect. When participants are strangers, income distribution is more equitable than when group membership is unchanged period after period.

At first it may be surprising that payoffs are more inequitably distributed in the partnered groups than in the randomly allocated groups. The standard deviations of individual payoffs by session in randomly assigned groups are lower than in partnered groups, regardless of group size. One possible explanation is that players in a partnered group have more opportunity to behave strategically. There are multiple Nash equilibria for participants in output sharing groups. Individual players can benefit from reducing their contributions while inducing others to raise theirs, but at the same time they do not want to trigger partners defection. Partners might, therefore, alternate contributions more than strangers and reciprocate more to groups members defection or cooperation.

There is no significant difference in the average contributions between strangers and in partners treatments. In groups of 4 partners contributed more effort on average than in stranger groups, while in groups of 6 the reverse is true. This seems to confirm the ambiguity of partners versus strangers outcomes in linear public goods experiments (Andreoni and Croson, 2002). The larger variance in the partner treatment is also consistent with the result of Croson (1996). Toward the end (the second half of decision periods) partners and strangers decisions converged and there was no significant difference, suggesting that one does not need to be concerned about the group allocation mechanism when this application is continuously repeated (as is the case for most CPRs).

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 without the extraction of rents by a regulator or prescribed appropriation limits may help implementation, in spite of the potentially increased dispersion of payoffs.

Communication between appropriators raises a problem for the output-sharing mechanism. 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 (to make them strangers) so that they do not have an opportunity to enter into tacit or explicit agreements regarding appropriation. It is, however, not always desirable to break up already existing cooperation in partnerships. Fishers often coordinate searching activities, and harvesters sometimes voluntarily cooperate in the extraction of stationary resources. Before breaking up stable groups and sustainable institutions, we need to evaluate, if communication is really presenting a problem for this mechanism. Communication might have the effect to reduce the variance of payoffs in partnered groups and reduce income inequality. Harvesters in partnered groups might even accept heterogeneity in payoffs if they acknowledge differences in skill or technologies. Evidence from our experiment indicates that income inequality differences vanish with the repetition in appropriation periods. The partner treatment, therefore, might very well have its place in specific contexts and CPR environments. We, therefore, thinks that the impact of communication on the output-sharing-partnership mechanism is worth exploring in future research.

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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.

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

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

Group Size	Group Allocation 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 Size	Group Allocation 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.

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

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 Allocation			
Group Size	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 Coefficients of Variation for Individual Payoffs per Session by Group Size and Group Allocation (standard deviations of the session coefficients of variation are in parentheses)*

	Group Allocation			
Group Size	No Output Sharing	Output Sharing: Partners	Output Sharing: Random Assignment	Row Totals
One-Person Groups	6.19 (2.24)			6.19 (2.24)
Four-Person Groups		7.63 (0.12)	5.19 (1.20)	6.41 (1.54)
Six-Person Groups		6.67 (1.97)	3.67 (0.45)	5.17 (2.08)
Column Totals	6.19 (2.24)	7.15 (1.35)	4.43 (1.16)	5.87 (1.86)

* 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 Coefficient of Variation of Individual Payoffs per Session)

Independent Variable	Coefficient	Standard Error	p-Value
Constant (Group Size One)	6.19	0.84	0
Group Size 4	1.44	1.19	0.252
Group Size 6	0.48	1.19	0.693
Random Allocation	-3.01	1.19	0.03
Group Size 4 and Random	0.57	1.68	0.742
Observations = 15	$R^2 = 0.566$	Adjusted $R^2 = 0.392$	$F(4, 10) = 3.26$ $p = 0.059$

Figure 3. Distributions of Individual Session Payoffs by Group Size