Output Sharing in Partnerships as a Common Pool Resource Management Instrument

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Abstract

Many economic environments are susceptible to either free-riding or overuse. Common pool resources (CPRs) fall in the latter category. Equally sharing the output of a CPR in partnerships introduces a free-riding incentive that may offset overuse. Socially optimal harvesting can be induced by dividing the set of resource users into a number of partnerships in such a way that each resource users' tendency to over-harvest from the resource is exactly offset by his or her tendency to free-ride on the contributions of others. We conduct a laboratory experiment to assess the performance of this partnership solution by introducing equal-sharing subgroups of size one, four and six into a twelve-person CPR environment. Group assignment is either unchanging throughout a 15 period session or randomly mixed each decision round. Group size significantly affects aggregate effort, while group assignment makes no significant difference. The distribution of total payoffs is more equitable for randomly mixed groups. Implications of our results for voluntary and centralized implementations of the partnership solution are discussed.

Key words: Common pool resources, partners and strangers, experimental economics, collective action, natural resource management

JEL classification codes: Q20, C91, D70, C92

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I. Introduction

Unregulated exploitation of a CPR results in excessive use of the resource.[1] This has been called the "tragedy of the commons" (Hardin, 1968). On the other hand sharing arrangements in partnerships induce free-riding behaviour in the form of reduced effort levels. This is often undesirable because it may give rise to instability of partnerships or necessitate monitoring and remuneration according to the supply of effort. Schott (2001), however, recognized that free-riding in partnerships could actually be beneficial when resource users are over-harvesting from a CPR such as a fishery. Sharing their harvest with others would provide independent harvesters with an incentive to reduce their effort. Socially optimal extraction could be induced by dividing the set of resource users into a number of partnerships in such a way that each resource user's tendency to over extract from the resource was exactly offset by his or her tendency to free-ride on the effort of others. This may be termed the "partnership solution" to the tragedy of the commons (Heintzelman et al., 2006).

The partnership solution has many potential advantages over other approaches to CPR management. Because resource rents remain with the resource users, it may be more politically acceptable than taxes or auctioned individual transferable quotas. Furthermore, it eliminates any incentive to discard unwanted by-catch or fish of inferior quality or size[2] since it neither restricts resource extraction nor places a price on each unit of effort or harvest. It could also facilitate adaptive management of the resource because adjustment of management targets would involve

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[1] Throughout this paper we use "extraction", "harvesting" and "appropriation" as equivalent terms for devoting effort to obtaining the product of a CPR.

[2] For documentation of the problems with by-catch and high-grading see, for example, Copes (1986), Parsons (1993), OECD (1997), Tietenberg (2002) and *The Economist* (2003).

changes in the size of partnerships, rather than changes in tax rates or quotas. Both taxes and quotas have been politically difficult to implement or change as witnessed, for example, in the collapse of the cod fishery in Eastern Canada. In this case politicians were reluctant to follow scientific recommendations to drastically reduce the annual total allowable catch from the end of the 1980s until 1992, when the stocks collapsed (Parsons, 1993).

The partnership solution is not a purely academic concept. There are several field examples of fishery partnerships that pool either catch or income. In Japan, for example, there are 147 of such fishing groups which engage in some form of pooling, some of which have been engaged in this form of CPR management for nearly half a century (Platteau and Seki, 2000). Carpenter and Seki (2004) and Platteau and Seki (2000) have examined pooling groups in Toyama Bay, Japan. They found that one group of seven boats successfully engaged in income pooling over several decades. Other groups pooled catch for a while but ultimately dissolved their partnerships because they consistently had too much catch dispersion and more productive members realized they would be better off on their own. As a result there are currently boats which pool catch or income with other boats and boats that do not engage in pooling. Pooling boats generally have larger catches and incomes.

When fishermen in pooling groups were surveyed for their rationale for pooling, the number one reason was to avoid crowding on limited spots (Platteau and Seki, 2000, table 13.2, page 362). Other reasons mentioned for pooling were to reduce the stress of racing, to avoid over-fishing and to share information. None of the fishermen mentioned stabilizing income or insurance reasons as a rationale for catch pooling. The experience in Toyama Bay shows that pooling catch across boats can increase incomes, even though this was not the announced motive for pooling. It is not clear, however, exactly what aspects of the mechanism operating in Toyama are generating the gains. It might be a direct reduction in effort due to free-riding arising from the pooling of revenues or a more subtle overcoming of problems by coordinating harvest locations or sharing information.

All this suggests that pooling output or incomes through partnerships may raise earnings in resource industries and perhaps help to sustain resource stocks. The strategy is popular with some resource users and, therefore, could prove to be a promising alternative management instrument, even for larger groups exploiting CPRs. Mandatory output-sharing could potentially solve common pool problems if a regulator could identify the optimal number of partnerships and then assign resource users to specific partnerships. The assignment of resource users could be anonymous in order to avoid collusion between partners, and could even be changed every harvest or extraction period. Schott (2001) demonstrates a theoretical basis for the potential of this mechanism.

The central feature of Schott's mechanism is offsetting the over-harvesting incentive found in CPRs by the free-riding incentive found in output-sharing. Laboratory experiments are an ideal way of identifying the effects of these variables while controlling many variables such as communication, reputation, differences in skill level, information sharing, and collusion in price setting, all of which are simultaneously changing in the field. The first goal of this paper is to evaluate the effect of mandatory output sharing in partnerships independently of these other variables. It is, therefore, a direct test of the “partnership solution” and its potential application in a regulator-mediated environment and an assessment of the non-cooperative impacts of catch-pooling arrangements in the field.

A practical problem in setting up an output-sharing arrangement in the field is the duration of partnerships. The proposition that free-riding incentives might just offset over-harvesting incentives is derived from the analysis of a one-shot, non-repeated game. This suggests that partnerships should be regularly re-mixed to approximate the theoretical model. On the other hand, the Toyama Bay example and perhaps other examples of output sharing in the field include groups with fixed memberships over relatively long durations. This set-up allows for repeated-games effects, including the building of reputations and the possibility of punishing shirkers through retaliation. It would be useful to know whether the rules for assigning group membership have a critical effect on the outcome of an output-sharing plan. Experimental evidence is inconclusive on the effect of group assignment ("partners" versus "strangers") in linear public goods games (Andreoni and Croson, 2005). This evidence is not directly applicable to the analysis of output sharing in partnerships both because the induced payoff function in the CPR environment is non-linear and because the output-sharing environment with its offsetting distortions is inherently more complicated. A second goal of this paper, therefore, is to investigate the effect of allowing fixed group membership (the partners treatment) in the outcome of a non-linear, common pool resource environment.

A potential threat to output sharing as a practical method for managing CPRs is widened income dispersion among harvesters. A single free-rider within an output-sharing group might earn significantly more than his harder working partners. If income is too unequally distributed it could cause individual harvesters to break up pooling agreements (as witnessed with some pooling groups in Toyama Bay). Income dispersion could also reduce the political feasibility of implementing the "partnership solution" in a more centralized environment through regulation by governments, regulatory boards or third parties. Consequently a third goal of this paper is to study the effect of output sharing arrangements on the distribution of individual incomes.

We approach our three goals by conducting an experiment in which participants are assigned to groups within which they pool revenues derived from the CPR. We systematically vary the size of the output-sharing group. The assignment of participants to groups is either fixed for the duration of the experimental session or randomly mixed after each decision round. The objectives of the experiment are (1) to test whether the size of the output-sharing group affects the aggregate level of extraction in the manner predicted by equilibrium non-cooperative game theory, (2) to determine whether the predicted effects (which are derived in the context of a single shot game) survive in the context of a repeated game and finally (3) to measure and describe the effects of group assignment and group size on the dispersion of individual incomes.

II. The Partnership Solution 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 focuses on the static externality problem and uses total effort applied to appropriation from a 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, 2001; Heintzelman *et al.*, 2006). 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 output is a function of the effort (X) allocated by all N individuals to appropriation from the CPR. The resulting total 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

$$^{k}\pi_i = w(^{k}e_i - {}^{k}x_i) + p(1/n)(^{k}X / X)Y \tag{1}$$

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, $^{k}e_{\mathrm{i}}$ is the individual's endowment of effort, p is the price of a unit of output from the CPR, $^{k}X = \Sigma_i\, {}^{k}x_i$ and $X = \Sigma_k\, {}^{k}X$. Assume that $p = 1$ and that all individuals are endowed with the same amount of effort, $^{k}e_{\mathrm{i}} = e$ for all k and i. Note that the k^{th} group receives a share of the CPR output Y equal to the relative effort it exerts, $^{k}X / X$, 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

$$\pi = wE - wX + Y \tag{2}$$

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

$$\partial Y/\partial\, {}^{k}x_i = w \tag{3}$$

The term on the left hand side ($\partial Y/\partial\, {}^{k}x_i$) will be identical for each individual in each group. The socially optimal profit is achieved 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 (as summarized by equation (1)) by individual i in group k with respect to effort put into appropriation is:

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

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

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

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

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

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

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

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

Finally, the optimal number of groups can be found. At an optimum, $\partial Y/\partial\, {}^{k}x_i = w$ and ${}^{k}X = (X/K)$, (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 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:

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

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 maximize the aggregate profit of the appropriators.

III. Experimental Design, Parameterization, and Predictions

The experiment consisted of 15 laboratory sessions each involving 12 participants. Each session involved 15 paid rounds of decisions in a modified common-pool resource environment. Participants were placed in output-sharing groups of one, four or six participants. Each period each participant received an endowment of 28 tokens. The tokens could be invested in one of two markets. Market 1 yielded a fixed return of 3.25 lab dollars (L$) per token invested. This represented the opportunity cost of effort spent appropriating from a CPR. Market 2 yielded a variable return that depended on the total investment in this market by all twelve participants. This represented the return from investing effort into appropriation from the CPR. Earnings from Market 2 were pooled across members of each group. Accordingly, each group received a payout equal to the tokens the group had invested in Market 2 multiplied by the average payout per token in Market 2. The group payout was then divided equally among the group members to determine the individual's payoff. In practice, participants chose only their investment in Market 2; all remaining tokens were invested in Market 1. Lab dollar payouts from Markets 1 and 2 were converted into Canadian dollars at the exchange rate L$2.00 = C$0.01.

There were five treatments: a control treatment in which there was no output sharing (group size was one) and four treatments with output sharing in groups of four or six. In one-half of the output-sharing sessions the group assignment was fixed across the fifteen decision rounds; in the remaining sessions group membership was randomly mixed each period. Three sessions were conducted for each of the five treatments. This design is presented in Table 1.

[Insert Table 1]

After receiving written instructions, which were also read aloud, participants made appropriation decisions in three practice rounds before beginning the fifteen paid decision rounds. In the random-assignment treatments, groups were mixed after every round including the practice rounds. In the partners treatments the groups were fixed for the three practice rounds, randomly mixed, and then held fixed for the remaining fifteen paid decision rounds. All interactions were mediated through a local computer network. 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 by computer.[3] Throughout the session participants could access online summaries of their contributions, the average contributions of others in their group, and the average contributions of others not in their groups. Communication among participants was not permitted.

The payoff structure is the same as that presented in equation (1) where the total output function is

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

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.[4] For these parameters, four-person groups should

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[3] Instructions and an example of the computer screen seen by a participant can be found in Appendices 1 and 2 at http://socserv.socsci.mcmaster.ca/~econ/mceel/papers/schottapp.pdf.

[4] For one-person, four-person and six-person groups the specific individual payoff functions are $\pi_i = 3.25(28 - x_i) + 32.5\, x_i - 0.09375\, x_i X$, ${}^k\pi_i = 3.25(28 - {}^kx_i) + (1/4)(32.5\, {}^kX - 0.09375\, {}^kX X)$, and ${}^k\pi_i = 3.25(28 - {}^kx_i) + (1/6)(32.5\, {}^kX - 0.09375\, {}^kX X)$ respectively.

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 effect of group assignment. For all hypothesis testing, the null hypothesis is that this treatment has no effect on effort, payoffs, or the distribution of payoffs.

The predicted levels of effort reported in Table 2 are unique equilibria for the groups and for the system as a whole. When group size exceeds unity, there are no unique equilibria for individual levels of effort. In the case of four-person groups, any combination of individual effort within the group totaling 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 effect of group size on the distribution of income is therefore indeterminate.

IV. Results

The experiment was run at the McMaster Experimental Economics laboratory. Participants were recruited from the general undergraduate population of McMaster University.[5] Average earnings were C$23.69 per participant (median C$23.87) for approximately ninety minutes in the laboratory. Cumulative payoffs ranged from C$18.89 to C$39.76 with a standard deviation of C$2.04. In this section we examine the aggregate effort devoted to appropriation from the CPR ("system effort") and the distribution of earnings across participants.

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[5] No attempt was made to control for sex, academic discipline, ethnicity or age of the participants. Participants were recruited through advertisements posted across campus and on the McMaster University Daily News website.

IV.1. Aggregate Effort

Because the observations on group contributions are clearly not independent, the analysis focuses on system effort by period and treatment. Figure 1 summarizes this data. It is immediately evident that the results are broadly consistent with the underlying theory. When there is no output sharing (group size is unity), mean system effort appears to converge to the Nash equilibrium of 288. 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. Their results appear to be robust to increases in the number of appropriators. As we increase the size of the output-sharing groups, aggregate effort applied to the CPR is clearly reduced. Moreover the observations for each group size lie close to the Nash equilibrium benchmarks, particularly in the later periods of each session.

[Insert Figure 1]

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. There is no noticeable effect of group assignment when the data are pooled across groups that share output (125 versus 128 tokens), however, the data pooled across group assignment show falling effort of 282 to 147 to 106 for output sharing groups of one to four to six people. We test the significance of these differences using an OLS regression with robust standard errors. We retain the null hypothesis of no difference between strangers and partners treatments for groups sizes of four and six persons separately ($F(1,10) = 0.59$, $p = 0.457$ for four-person groups and $F(1,10) = 0.83$, $p = 0.384$ for six-person groups) and together ($F(1,10) = 0.11$, $p = 0.745$). The same regression shows that the effort exerted by one-person groups is significantly greater than effort exerted by four-person groups, which in turn is significantly greater than effort exerted by six-person groups ($t = 28.493$, $p = 0.000$ and $t = 5.258$, $p = 0.000$ respectively).[6]

[Insert Table 3]

Figure 1 suggests that after fifteen periods the system effort from each treatment approximates the predicted Nash equilibrium for each group size. To evaluate the convergence patterns for each of the five treatments, the asymptotic effort for each treatment is estimated using a procedure similar to that of Noussair *et al*. (1995). The model estimated is

$$X_{i\,t} = \Sigma_{\mathrm{i}}\, \beta_{1\,i}\, (1/t) + \beta_2\, (t\text{-}1)/t + u_{i\,t} \qquad i = 1, 2, 3 \tag{10}$$

where $X_{i\,t}$ is the system effort of session i in period t, β_{1i} is an estimate of the first period's system effort in session i and β_2 is an estimate of the effort to which session i would converge over time. There are 45 observations for each treatment's regression (three 15 period sessions). The regression is estimated using the Cochrane-Orcutt technique for AR1 processes. The estimated asymptotic effort for each treatment and the corresponding p-values associated with tests of the null hypotheses that effort to appropriate from the CPR converges asymptotically to the static Nash equilibrium predictions for the treatments are presented in Table 4. Examining the 95% confidence intervals we retain the null of no difference from Nash equilibrium in three of five cases: one-person groups and both treatments involving six-person groups. In the cases

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[6] The details of the regression results reported here and others reported later in the text are posted in Appendix 3 at http://socserv.socsci.mcmaster.ca/~econ/mceel/papers/schottapp.pdf . The regressions are of the general form $D = a + bG4 + cG6 + dRA + eRA\text{x}G4$, where D is the relevant dependent variable, $G4$ is unity if the group has four people and zero otherwise, $G6$ is unity if the group has six people and zero otherwise, RA is unity if the assignment of people to groups is random and zero otherwise, $RA\text{x}G4$ is an interaction term taking the value of unity for groups of size four with random assignment, and a captures the value of the dependent variable for single person groups.

of the four-person groups we do reject the null that asymptotic effort equals the Nash equilibrium. Although 4-person groups are the only ones which do not tend to converge to the predicted Nash equilibrium, we are not inclined to place much weight on this result.[7]

[Insert Table 4]

IV.2. Payoffs to Participants in the CPR

In addition to knowing whether or not output sharing provides the appropriate incentives to correct the over-appropriation that 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 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 average individual payoff in a period reaches a maximum at the socially efficient group size of four.

[Insert Figure 2]

Figure 2 displays the distributions of session payoffs for individual participants by group size pooled across the fixed and random assignment treatments. These distributions report the proportion of the individuals in the group which have a payoff in a particular range. The ranges are in increments of hundreds of lab dollars. For example, an observation at L$3500 reports the

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[7] Note that the point estimates for asymptotic effort (141 and 143 for partners and strangers respectively) lie quite close to the static Nash equilibrium prediction of 156. It is the low standard errors that lead to rejection of the null. Using estimated root mean square deviation (RMSD) of asymptotic effort from Nash as an alternative criterion for closeness to the predicted Nash equilibrium we find that 4-person groups (RMSD = 13.82 and 15.72) are intermediate between the 6-person strangers groups (RMSD = 25.54) and the 6-person partners group (RMSD = 4.58). Thus we are reluctant to put strong weight on the rejection of Nash equilibrium in the case of 4-person treatments.

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 session 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 participants with the lowest payoffs in any of the output-sharing experiments had larger session payoffs than the participants who had the largest payoffs in any of the appropriation experiments without output sharing. In contrast, the frequency distributions for four- and six-person groups overlap considerably.

[Insert Table 5]

Table 5 cross-tabulates mean individual payoff per person by group size and group assignment. There is one observation for each session. 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. Group assignment does not appear to have a substantial effect on mean individual payoffs for output-sharing groups. An OLS regression using robust standard errors confirms that the mean payoffs in the fixed assignment condition are not significantly different from the mean payoffs in random assignment condition ($t = 0.600$, $p = 0.561$), but that the payoffs realized by one-person groups are significantly less than payoffs realized by four-person groups, which in turn are significantly greater than payoffs realized by six-person groups ($t = 30.184$, $p = 0.000$ and $t = 4.957$, $p = 0.000$ respectively). These results are not surprising. They reflect the results for system effort described earlier.

The results that may be of particular interest, however, concern the variation in individual payoffs per session. We find that inequality is significantly affected by group assignment (fixed or random), even though there is no strong theoretical explanation for this phenomenon. We measure inequality by the coefficient of variation of the total payoffs to individuals in each session.[8] The summary statistics are reported in Table 6.

[Insert Table 6]

The values reported in Table 6 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 group size of four with fixed assignment). There is no systematic effect of group size. The row totals show the greatest dispersion of individual payoffs for groups of four and least for groups of six. The one-person groups show an intermediate dispersion of cumulative payoffs. None of these differences is substantial. In contrast, the column totals show a substantial effect of the group assignment treatment on the dispersion of cumulative payoffs in output-sharing groups. The mean coefficient of variation is much lower in the random assignment condition (4.43 versus 7.15). An OLS regression using robust standard errors confirms these observations. The group assignment effect is statistically significant ($t = 4.015$, $p = 0.003$). The mean coefficient of variation for one-person groups (6.19) is intermediate between the two output-sharing treatments, and is not significantly different from the mean coefficient of variation for all output-sharing groups combined (mean 5.79, $t = 0.300$, $p = 0.772$).

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[8] 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 assignment to group changes, the payoffs to appropriators from the CPR change. To compare the distributions of income across the different treatments, a measure that 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 session payoff distribution will lead to a conclusion that session payoff distribution has become more equitable if the mean payoff increases but the standard deviation of the payoff does not change. Session payoff distribution becomes less equitable only if the standard deviation of payoffs increases (decreases) by more (less) than the mean payoff rises (falls).

The significant effect of group assignment on the dispersion of individual payoffs per session is unexpected. One possible explanation is that players in the fixed assignment groups have more opportunity to behave strategically. The repeated nature of the game gives them an opportunity to choose their current effort level in an attempt to manipulate others' future choices. Individual players can benefit from choosing a low effort level if reducing their effort causes others in their group to follow their best-response functions and increase their effort. This strategy is unavailable in the random assignment treatment because participants do not know the effort made last period by others in their group and consequently cannot compute a best response. As a result we might expect a lower period-to-period variation in levels of effort in the partners treatment than in the strangers treatment. This low variation can lock the participants in the partners treatment into a certain dispersion of income. This may result in a lower dispersion in session payoffs in strangers treatments than in partners treatments.

There is some weak support for this conjecture. A robust OLS regression of the mean standard deviation of individual effort levels (one observation per session) shows that the mean standard deviation in the strangers treatment is about 10 percent higher than in the partners treatment. The difference is only very weakly significant ($p = 0.103$ on a one-tail test) but consistent with our expectations.

V. Summary and Discussion

Sharing output in partnerships has the potential for controlling the oversupply of effort devoted to harvesting from a common pool resource. The mechanism is observed in the field and can be modeled theoretically. The experiment described here is a first attempt to evaluate it in a controlled environment with human decision-makers. The objectives of the experiment were first to test whether observed behaviour conforms to a simple model of the mechanism, second to determine whether the predicted effects (which are derived in the context of a single shot game) survive in the context of a repeated game and finally to measure and describe the effects of group assignment and group size in the dispersion of individual incomes.

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 this effect increases with group size. This result holds both in the random assignment condition (which corresponds most closely to the theoretical model) and in the fixed assignment condition. Effort levels in both treatments conform closely to the one-shot Nash equilibrium. Output sharing significantly raised the individual payoffs compared to the control condition. Individual payoffs were higher at the theoretically optimal group size of four than at the larger group size of six. The dispersion of individual incomes, as measured by the coefficient of variation of cumulative payoffs, is not substantially changed with the introduction of output sharing. It is affected, however, by the method of assigning groups. Income inequality was substantially reduced in the random-assignment condition, particularly in six-person groups.

The results for our control condition are similar to those obtained by Ostrom, Walker and Gardner (1994) in a similar environment. This suggests that our results are not due to any idiosyncratic aspects of the experimental design. The lack of significant effects of group assignment conforms to Andreoni and Croson's (2005) comparison of partners and strangers treatments in linear voluntary contribution models and extends their observation to the case on non-linear common pool resource environments.

Our experimental results suggest that output sharing is worth considering as an instrument for the management of common pool resources. If either resource users or a regulator could discover the optimal group size for a CPR, the imposition of output-sharing partnerships could lead to efficient exploitation of the resource in the sense that resource rents are maximized.[9] Successful imposition, however, requires 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. The effect of output sharing on income distribution is one important factor in the acceptance of such plans. Our results suggest that the overall distribution of income may be more equitable, and hence output-sharing will be more palatable, when groups are randomly mixed at frequent intervals. This effect of random assignment prevails only in the long run, however, after independent variation in period-by-period earnings has averaged out. A plan that provides high variance in annual incomes may not be politically attractive, even if it reduces the variance in lifetime incomes. There are, of course, other barriers to implementing it in the field. Income changes may not be a good measure of actual welfare changes if individual utility functions are interdependent

The output-sharing mechanism studied in the laboratory could also be extended to capture other salient features of the field. Heterogeneity in the individual cost of effort (as a proxy for skill level), the impact of individual disclosure of effort and the opportunity to communicate with others may be important in understanding the attributes of the output-sharing mechanism. Endogenizing the formation of output-sharing groups within the CPR could provide

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[9] On conventional cost-benefit criteria this is a desirable outcome. If individuals' utility functions are interdependent, it may no longer be possible to draw welfare conclusions from increases in incomes. For example, an individual's welfare may be reduced by observing free-riding by other members of his group or by over-harvesting by other groups. Such reactions may lead to punishment of offenders and retaliation of punished offenders, this further complicates welfare analysis.

a test of the predictions of Heintzelman *et al*. (2006) with regard to the stability of the partnership solution. The present paper offers a firm foundation for this future research.

References

Andreoni, J. and Croson, R., 2005. “Partner versus Strangers: Random Rematching in Public Goods Experiments” in *Handbook of Experimental Economics Results*, edited by Charles R. Plott and Vernon L. Smith. Amsterdam: Elsevier (forthcoming).

Brown, G., 1974.“An Optimal Program for Managing Common Property Resources with Congestion Externalities”. *Journal of Political Economy* 82, 163-174.

Carpenter, J. and E. Seki, October 2004. “Do Social Preferences Increase Productivity? Field Experimental Evidence from Fishermen in Toyama Bay”. *Unpublished Working Paper*.

Copes, P., 1986. “A Critical review of the Individual Quota as a Device in Fisheries Management”. *Land Economics* 62, 278-291.

Dasgupta, P. S. and G. M. Heal, 1979. *Economic Theory and Exhaustible Resources*. Cambridge: Cambridge University Press.

The Economist, February 24, 2003. Turtle Power-Bycatch from Fishing is a Bigger Problem than was Realized.

Hardin, G.,1968. “The Tragedy of the Commons”. *Science* 162, 1243-1247.

Heintzelman, M.D., Salant, S.W. and Schott, S., February 2006. “Coordination and Free-Riding: A Partnership Solution to the Common Property Problem”, *SPPA Working Paper*, http://www.carleton.ca/sppa/Publication/index.html.

Noussair, C. N., C. R. Plott, and R. G. Riezman, 1995. “An Experimental Investigation of the Patterns of International Trade”. American Economic Review 85, 462-491.

OECD, 1997. *Towards Sustainable Fisheries: Economic Aspects of the Management of Living Marine Resources.* Paris: Organization for Economic Co-operation and Development.

Ostrom, E., R. Gardner and J. Walker, 1994. *Rules, Games, and Common-Pool Resources*. Ann Arbor: The University of Michigan Press.

Parsons, L.S., 1993. *Management of Marine Fisheries in Canada*, National Research Council of Canada and Department of Fisheries and Oceans: Ottawa, Ontario.

Platteau, J.-P. And E. Seki, 2000. "Community Arrangements to Overcome Market Failure: Pooling Groups in Japanese Fisheries". In *Communities and Markets in Economic Development*, edited by M. Aoki and Y. Hayami. Clarendon Press: Oxford.

Schott, S., 2001. "A Partnership Solution to the Tragedy of the Commons". *4th Toulouse Conference on Environment and Resource Economics*, Toulouse, France, May 2001.

Tietenberg, T., 2002. "The Tradable Permits Approach to Protecting the Commons: What Have we Learned?", in *The Drama of the Commons*, edited by E. Ostrom, T. Dietz, N. Dolsak, P.C. Stern, S. Stonich and E.U. Weber, Washington, D.C.: National Academy Press, 197-232.

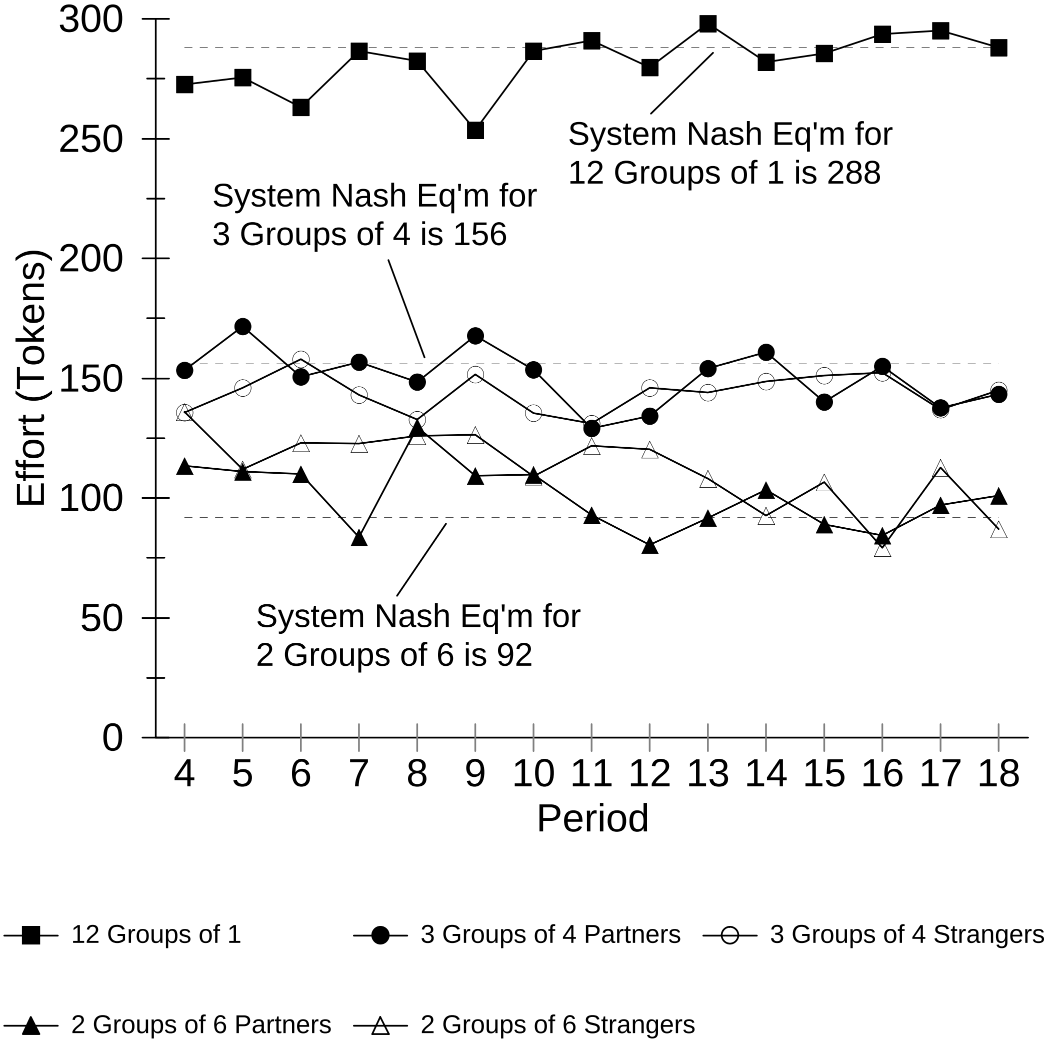

Figure 1 Mean System Effort by Group Size and Group assignment

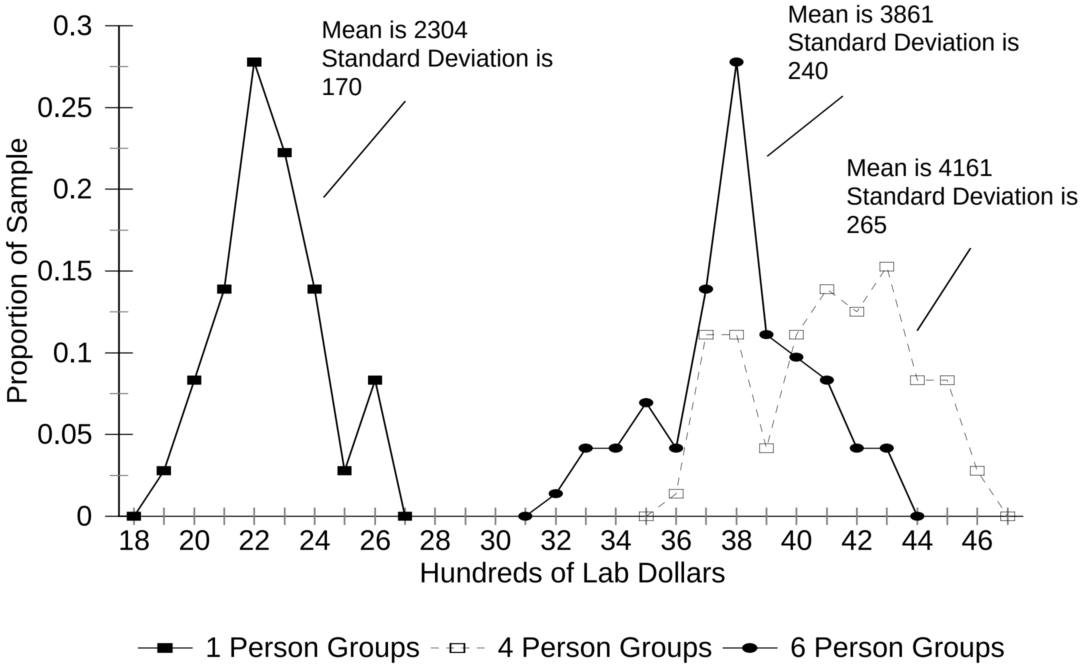

Figure 2 Distributions of Individual Session Payoffs by Group Size

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

Group Size	No Output Sharing	Group Assignment	
		Output Sharing: Fixed Assignment	Output Sharing: Random Assignment
One-Person	3		
Four-Person		3	3
Six-Person		3	3

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

Group Size	System Effort per Period (Tokens Appropriated)*	Group Effort per Period (Tokens Appropriated)*	Mean Individual Session Payoff in Lab Dollars
One-Person	288	24	2175
Four-Person	156	52	4217
Six-Person	92	46	3737

* 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. Mean System Effort per period by Group Size and Group Assignment based on Session Data (standard deviations are in parentheses)*

Group Size	No Output Sharing	Group assignment: Output Sharing: Fixed Assignment	Group assignment: Output Sharing: Random Assignment	Row Totals
One-Person	282.24 (3.59)			282.24 (3.59)
Four-Person		150.42 (9.04)	143.82 (11.69)	147.12 (10.02)
Six-Person		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. Asymptotic Estimates of Effort by Treatment

Treatment	Asymptotic Effort	Robust Standard Error	p-value	95% Confidence Interval
One-Person	289	2.765	0.709	283 to 295
Four-Person Fixed Assignment	141	4.704	0.004	132 to 152
Four-Person Random Assignment	143	4.703	0.007	133 to 152
Six-Person Fixed Assignment	92	4.578	0.921	82 to 101
Six-Person Random Assignment	73	17.065	0.284	39 to 108

* Estimates are derived from a robust OLS regression corrected for AR1 autocorrelation using the Cochrane-Orcutt technique. p-values are for tests of the null hypotheses that there are no differences between the estimated asymptotic efforts for the treatments and the predicted static Nash equilibrium efforts for corresponding treatments. The standard errors and p-values are adjusted for heteroscedasticity using a Huber/White sandwich error adjustment.

Table 5. Mean Individual Payoff per Session by Group Size and Group Assignment (standard deviations of the session means are in parentheses)*

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

* There are three sessions for each treatment.

Table 6. Mean Coefficients of Variation for Individual Payoffs per Session by Group Size and Group Assignment (standard deviations of the session coefficients of variation are in parentheses)*

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

* There are three sessions for each treatment.