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THE ROLE OF COMMUNICATION IN RESOLVING COMMONS DILEMMAS: EXPERIMENTAL EVIDENCE WITH HETEROGENEOUS APPROPRIATORS

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Communication has been shown to be an effective mechanism for promoting efficient appropriation in small homogeneous common-pool resource settings. Communication allows appropriators the opportunity to agree on an aggregate appropriation target, and coordinate over the selection of allocation rules. When appropriators are identical, these rules result in identical allocations, which facilitates coordination. We examine the robustness of communication as an efficiency-enhancing mechanism in settings where appropriators differ in size, as measured in appropriation capacity. This heterogeneity creates a distributional conflict over the allocation of access to common-pool resources. This conflict can cause self-governance to fail. We present findings from a series of experiments where heterogeneous endowments are assigned: 1) randomly, and appropriators have complete information, 2) through an auction, and appropriators have complete information, and 3) randomly, and appropriators have incomplete and asymmetric information. These findings are contrasted with allocation rules from the field.

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I. INTRODUCTION

Common-pool resources (CPRs) are defined to be natural or man-made resources in which: (a) exclusion is nontrivial (but not necessarily impossible) and (b) yield is subtractable (Ostrom, Walker, and Gardner, 1992). Individuals jointly using a CPR are assumed to face a social dilemma -- often called the tragedy of the commons -- in which individually rational resource users ignore the external harm they impose on other users, leading to outcomes that are *not* rational from the perspective of the group. Policy proposals for resolving CPR dilemmas often follow one of two approaches--privatizing the resource or centralizing its management within the state. As a result, a single owner or regulator is deemed necessary if resource dilemmas are to be resolved and resources used efficiently (Ophuls, 1973). A growing body of field and experimental literature, however, provides considerable evidence that resource users confronted with CPR dilemmas may adopt self-governing organizations that enable them to resolve their dilemmas.[1]

One critical component of institutions devised for promoting cooperation in CPR settings is face-to-face communication among resource users. Even though noncooperative game theory suggests that communication should play no strategic role (at least in finitely repeated games), numerous experiments involving face-to-face communication in social dilemma settings suggest otherwise. As Dawes (1980) states, "The salutary effects of communication on cooperation are ubiquitous" (p. 185).[2] On the other hand, individuals who are permitted to communicate do not always achieve optimal outcomes. The rule structure of permitted communication, as well as the complexity of the social dilemma setting, affects the robustness of communication in promoting cooperation. For instance, Ostrom, Walker and Gardner (1992), investigating communication in a CPR decision environment, found significant differences in the impact of communication in situations which differed according to: (1) whether communication opportunities were one-shot or repeated and (2) whether "noncooperative decisions" by a given individual were sufficiently disruptive to deter cooperation among other appropriators. Further, the research of others such as Orbell, van de Kragt, and Dawes (1988), Isaac and Plott (1981), Isaac, Ramey, and Williams (1984), Isaac and Walker (1985) demonstrate the importance of the particular decision setting (the institutional rules for exchange) in promoting the success of communication as an independent mechanism.

Understanding the robustness of face-to-face communication as a mechanism for facilitating cooperation in more complex decision settings is critical to understanding the evolution of self-governing institutions. Most experimental research on communication has focused on collective action problems in which individuals are homogeneous in decision attributes. It is possible that the strong efficiency enhancing properties of face-to-face communication are dependent upon homogeneities in decision attributes. In fact, the literature provides several arguments that point to heterogeneity as a serious deterrent to cooperation (Hardin 1982, Johnson and Libecap 1982, Libecap and Wiggins 1984, Isaac and Walker 1988, Wiggins and Libecap 1987, Ostrom 1990, Kanbur 1991, Hackett 1992). For example, Kanbur (1991, 21-22) argues,

> ... theory and evidence would seem to suggest that cooperative agreements are more likely to come about in groups that are homogeneous in the relevant economic dimension, and they are more likely to break down as heterogeneity along this dimension increases.

The task of agreeing to and sustaining agreements for efficient CPR appropriation is more difficult for heterogeneous appropriators because of the distributional conflict associated with alternative allocation rules. In heterogeneous settings different allocation rules produce different distributions of resources across appropriators. While all appropriators may be made better off by cooperating, some will benefit more than others, depending upon the allocation rule chosen. Consequently, appropriators may fail to cooperate on the adoption of an allocation rule because they cannot agree upon what would constitute a fair distribution of benefits produced by cooperating.[3]

Building on the experimental research of Ostrom, Walker, and Gardner (1992), this paper examines the effects of size heterogeneities on the ability of individuals to coordinate their use of a CPR.

By size heterogeneities we mean that individuals differ in their appropriation capacity. Size heterogeneities imply that rules adopted to reduce over-appropriation from the CPR will have differential effects on earnings potential across experimental subjects. Before turning to the laboratory study, section II examines the case study literature and reports on allocation rules observed in a diverse set of naturally-occurring CPRs. This sample of field studies provides a benchmark for discussing the distributional implications of alternative rule types and creates a basis for understanding rules adopted in the laboratory. Section III presents the decision setting for our experimental study. Section IV discusses initial results from experiments where heterogeneities were assigned either randomly or using an auction mechanism that made being large in appropriation capacity costly to the subjects. Section V examines the robustness of our initial findings by exploring a situation with incomplete and asymmetric information regarding other appropriators' endowments. Section VI contains concluding comments.

II. CPR ALLOCATION RULES FROM THE FIELD

Common allocation rules used among heterogeneous appropriators in field settings include proportional allocation, equal withdrawal, or some combination of the two. Table 1 presents summary characteristics from a sample of field settings where allocation rules were adopted.[4] This summary illustrates the variety of rules adopted in the field and serves as a focus for comparing distributional characteristics of alternative rule types.

As Table 1 illustrates, *proportional rules* are commonly adopted among heterogeneous appropriators, with the basis for proportionality dependent upon a variety of factors. Appropriation rights are often proportionate to historic use levels, or to the quantity of land owned by resource users. For instance, groundwater pumpers in southern California reduced pumping in a manner proportionate to historic pumping levels to prevent the over-mining of groundwater basins (Blomquist, 1992).

Alternatively, the irrigators of Valencia, Spain have been allocating irrigation water proportionate to land ownership since medieval times (Maas and Anderson, 1986).

> Proportionality was the organizing factor of the water distribution systems of medieval eastern Spain. Each irrigator received water in proportion to the amount of land he held. The water to which he was entitled, moreover, was not a fixed amount per unit of land, but rather a proportional one which varied with the volume of the river. All irrigators shared in times of abundance and were equally deprived in times of drought (Glick 1970: 207).

Proportional allocation of water based on the amount of land held is also the organizing rule among irrigators located in the coastal lowlands in the province of Ilocos Norte, Philippines (Coward 1979). Within the irrigation system are a fixed number of shares called <u>atars</u>. An atar consists of several noncontiguous parcels of land. "The supply of water available in the system at any given time is shared proportionally among the shareholders of the system", based upon the number of atars owned (Coward 1979:31). In addition to allocating water proportionally, the costs of operating the irrigation system are proportionally shared. That is, "the resources required to operate the system are requested from the water users in proportion to the shares they hold" (Ibid.). Finally, if there is insufficient water to irrigate all of the land, the amount of land that can be irrigated is determined and the farmers "have their total farm size reduced proportionately" (Coward 1979:30). Proportional allocation rules are conservative in the sense that they maintain relative resource allocations at the status quo level. For example, if an appropriator historically withdrew three times as much as another appropriator, then that difference would be maintained after the adoption of a proportionate allocation rule.

An alternative allocation rule, *equal withdrawal*, involves a redistribution of resources which alters the status quo level of heterogeneities among appropriators. With an equal withdrawal rule, a common ceiling is placed on all individual withdrawal levels. Appropriation heterogeneities are minimized, as all appropriators are permitted to withdrawal only up to a certain amount. Such allocation rules are often found in situations in which size heterogeneities are minimal, such as the scallop fishers in the state of Victoria in Australia, where quotas were imposed to prevent the over-harvesting of scallops (Sturgess, et.al. 1982).

There are, however, instances in which an equal withdrawal rule has been used among appropriators with substantial heterogeneities. For example, equal withdrawal rules are used on an irrigation system in India, in the village of Sukhomajri (Seckler and Joshi 1982). The irrigation system for the village was created through an international development project. The project coordinators decided to allocate an equal amount of water to each landholder (Seckler and Joshi 1982:28). A water users association later took over the management of the irrigation system and changed the allocation rule to include landless villagers.

> Each **bona fide** family in the village--any group eating from a common hearth in Indian culture--is given a water coupon entitling them to the same quantity of water as any other family, irrespective of land ownership. The family can trade, give away, or sell the coupons as they wish, but with the approval of the Water Users Association (Seckler and Joshi 1982:30).

Similarly, the Sonjo irrigators in the village of Kheri, located in northern Tanzania near the Kenya border, use an equal appropriation rule based on time. The source of their irrigation water is small streams and springs. In most years "the water is completely used up for irrigation during the dry months and is therefore regarded as a scarce commodity..." (Gray 1963:47). "Primary rights for water are assigned to an individual for a full six hour period" (Gray 1963: 58). Approximately 35 men in the village hold hereditary rights to the water. All other farmers must acquire water from these men.

> An individual of the privileged categories seldom requires all the water for the six hours to which he is entitled--even one with large landholdings--and frequently two hours is sufficient to soak his plots. The water that is left over may then be distributed to the men who are without any special rights" (Gray 1963:59-60).

Men who do not have hereditary rights to water are often required to pay fees or pay other compensation for the water they acquire.

In some field settings a combination of proportionate reduction in appropriation and an equal withdrawal rule are used. Such rules generally provide a minimal appropriation right for all appropriators, but permit differences in withdrawal levels beyond the minimum. For example, in 1982, the Ontario Ministry of Natural Resources and the Ontario Council of Commercial Fisheries created a new management plan that included individual transferable harvest quotas for Lake Erie (Berkes and Pocock, 1987). The plan was implemented in 1984 to address the over-harvesting of yellow perch, smelt, white bass, and walleye. Prior to implementation conflict emerged over how individual quotas should be allocated.

> Polls taken at the local association level indicated that the majority of fishermen at that time preferred an 'equal split' formula within each licensing area, whereby all fishermen in an area would get the same quota (Berkes and Pocock 1987:497).

The allocation formula eventually adopted, however, was based "on landings by license in the previous 10 years" (Ibid.). In other words, the Ministry adopted a proportionate reduction from historic harvesting levels as an allocation rule. A number of problems emerged, resulting in quota adjustments over subsequent years. For instance, in 1984, Port Stanley fishermen threatened to blockade the local harbor. Following this, the ministry granted an additional quota based on equal shares. In 1985, additional quotas were granted to fishermen in all of Lake Erie. In eastern Lake Erie, "license holders...voted on an allocation mechanism to distribute the extra quota, and a majority (44 to 33) opted for 'equal split'" (Berkes and Pocock 1987:498). The fishermen of western Lake Erie responded differently to the additional quotas by changing the allocation rule to reduce inequities in the quotas.

> The change established a formula with one-third equal share as a base and two-thirds on the basis of past performance. It was a compromise to satisfy the fishermen at the lower end of the quota scale, without reducing the quotas of those at the upper end (Ibid.).

An additional rule that appropriators could use, although one that we did not find in the case study literature, is an *equal absolute reduction rule*. Such a rule would require all appropriators to reduce their withdrawal levels by an equal and absolute amount. Since smaller appropriators would be required to proportionately cut back more than larger sized appropriators, an equal absolute reduction rule would exaggerate existing heterogeneities among appropriators.

Clearly, as the above discussion of rules illustrates, different appropriation rules imply different costs for appropriators. Preferences across allocation rules will differ between large and small appropriators. Of the rules discussed thus far, large appropriators would prefer an equal absolute reduction rule the most. This is because they would be required to cut back their withdrawal activities the least relative to the other rules. On the other hand, large appropriators would prefer an equal withdrawal rule the least because they would be required to cut back their withdrawal activities the most relative to the other rules. Small appropriators would have the opposite preference ordering. An equal withdrawal rule would require small appropriators to cut back their withdrawal activities the least relative to the other rules. In contrast, an equal absolute reduction rule would require small appropriators to cut back their withdrawal activities the most.

Among heterogeneous appropriators there will generally be no rule that is universally preferred to all other rules. Consequently, appropriators are likely to disagree over the type of rule to adopt even though they may agree that they would be better off as a group if they reduced appropriation levels. It is such conflict over preferred allocation rules that may prevent heterogenous appropriators from adopting a specific rule. Our experimental decision environment is designed to further explore the relationship between size heterogeneity and self-governance. In a controlled setting we are able to more closely examine the evolution of successful agreements, and measure the degree to which nonbinding agreements enhance efficiency. We now turn to a discussion of the decision environment examined in our laboratory investigation, and then to results.

III. THE EXPERIMENTAL CPR DECISION ENVIRONMENT

Theoretical Predictions

The Single-Play CPR Game

We first describe the class of single-play CPR games from which we draw our designs. Assume a fixed number n of appropriators with access to the CPR.[5] Each appropriator i has an endowment of resources e_i which can be invested in the CPR or invested in a safe, outside activity.

The marginal payoff of the outside activity is normalized equal to w. The payoff to an individual appropriator from investing in the CPR depends on aggregate group investment in the CPR, and on the appropriator's investment as a percentage of the aggregate. Let x_i denote appropriator i's investment in the CPR, where $0 \leq x_i \leq e_i$. The group return to investment in the CPR is given by the production function $F(\Sigma x_i)$, where F is a concave function, with $F(0) = 0$, $F'(0) > w$, and $F'(\Sigma e_i) < 0$. Initially, investment in the CPR pays better than the opportunity cost of the foregone safe investment $[F'(0) > w]$, but at some level of appropriation (x_b) the outcome is counterproductive $[F'(x_b) < 0]$. Thus, the yield from the CPR reaches a *maximum net level* when individuals invest some but not all of their endowments in the CPR.[6]

Let $x = (x_1,...,x_n)$ be a vector of individual appropriators' investments in the CPR. The payoff to an appropriator, $u_i(x)$, is given by:

$$\begin{array}{ll} we_i & \text{if } x_i = 0 \\ w(e_i-x_i) + (x_i/\Sigma x_i)F(\Sigma x_i) & \text{if } x_i > 0. \end{array} \qquad (1)$$

Equation (1) reflects the fact that if an appropriator invests all his endowments in the outside alternative, he gets a sure payoff (we_i), whereas if he invests some of his endowment in the CPR, he gets a sure payoff $w(e_i-x_i)$, plus a payoff from the CPR. An appropriator's payoff from the CPR depends on the yield from total investment, $F(\Sigma x_i)$, multiplied by his share of overall group investment $(x_i/\Sigma x_i)$.[7] Previous studies have simplified the analysis of the CPR game by using designs that yield fully symmetric non-cooperative investment equilibria. To see this, let the payoffs in (1) be the payoff functions in a symmetric, noncooperative game. Then each player invests x_i^* in the CPR such that:

$$-w + (1/n)F'(nx_i^*) + F(nx_i^*)((n-1)/x_i^*n^2) = 0. \qquad (2)$$

The focus of this paper, however, is on appropriator heterogeneity. In particular, the experiment allows for two levels of appropriator endowments. One subset of appropriators have large endowments, e_i^l, $i=1,2,\ldots,M$; the remaining appropriators have small endowments, e_j^s, $j=M+1,M+2,\ldots,N$, and $e_i^l > e_j^s$ (superscripts refer to endowment size). Parameters are chosen so that the Nash equilibrium is symmetric within appropriator type, but asymmetric across type; large appropriators make a greater investment in the CPR than small appropriators.[8] This is accomplished by having the small players' endowment be a binding constraint in equilibrium. Investments at the Nash equilibrium satisfy:

$$-w + (x_i^*/(Z+Mx_i^*))F'(Mx_i^*) + F(Mx_i^*)[Z+(M-1)x_i^*]/(Z+Mx_i^*)^2 = 0 \tag{3a}$$

for $i=1,2,\ldots,M$ large endowment players, and

$$x_j^* = e_j, \tag{3b}$$

for $j=M+1,M+2,\ldots,N$ small endowment players ($Z \equiv \Sigma x_j^*$). Group investment in the CPR at this asymmetric Nash equilibrium is greater than optimal, but not all rents from the CPR are dissipated (CPR *rents* per unit of investment are defined here to be the average revenue product of investment in the CPR, less the average revenue product of investment in an outside opportunity). To see this, compare this deficient equilibrium to the optimal solution. Summing across individual payoffs $u_i(x)$ for all appropriators i, one has the group payoff function u(x),

$$u(x) = w\Sigma e_i - w\Sigma x_i + F(\Sigma x_i), \tag{4}$$

which is to be maximized subject to the constraints $0 \leq \Sigma x_i \leq \Sigma e_i$. Given the above conditions on F, the group maximization problem has a unique solution characterized by the condition:

$$-w + F'(\Sigma x_i) = 0. \tag{5}$$

According to (5), the marginal return from a CPR should equal the opportunity cost of the outside alternative for the last unit invested in the CPR. While the asymmetric Nash equilibrium depends critically on the endowment parameter e_i, the group payoff maximizing level of investment does not. There are many different allocation rules that can distribute individual investments in the CPR such that overall group investment maximizes CPR rents. Since endowments are heterogeneous, different rules (e.g., equal investment in the CPR versus CPR investment proportionate with endowment) imply different wealth distributions. Such inequities may invoke disagreement over the type of allocation rule, and ultimately a reduction in CPR rents.

Finite Repetition

Denote the CPR game by X and let X be played a finite number of times.[9] If the game has a unique equilibrium, then the finitely repeated game has a unique subgame perfect and subgame consistent equilibrium (Selten 1971). Thus, equation (3) characterizes a finite sequence of equilibrium outcomes. This prediction is based on the assumption of a finite game of complete information. Our subjects know the game is finite.[10] Although we do not have complete control over our subjects' understanding of their decision task, we make all information readily available to them.

Communication

Face-to-face communication represents an interesting empirical anomaly. In a finitely repeated, complete information setting, noncooperative game theory ascribes no strategic content to nonbinding communication.[11] From field and laboratory settings, however, this institution fosters significant change in behavior.

In order for communication to enhance joint CPR payoffs, the appropriators must agree on (i) the target level of group investment, (ii) a rule for allocating the target investment level to the appropriators, and create (iii) the necessary "social capital" to attenuate cheating, since agreements are nonbinding. The existence of heterogeneity in endowments and in historic investment levels has no effect on (i), but presumably elicits disagreement over (ii), which in turn may impair (iii). The research goal is to observe the effect of endowment heterogeneity on the success of communication as a rent-enhancing mechanism, and on the form and success of allocation rules endogenously chosen by the subjects. Such rules can then be contrasted with those reported in section II.

The Laboratory Setting and Design

Subjects and the Experimental Setting

The experiments reported in this paper used subjects drawn from the undergraduate population at Indiana University and the University of Arizona. Students were volunteers recruited from undergraduate economics, political science, and public administration classes. Prior to recruitment, potential volunteers were given a brief explanation in which they were told only that they would be making decisions in an "economic choice" environment and that the money they earned would be dependent upon their own investment decisions and those of the others in their experimental group. All experiments were conducted on the NovaNET computer system. The computer facilitates the accounting procedures involved in the experiment, enhances subject control across experiments, and allows for minimal experimenter involvement.

At the beginning of each experimental session, subjects were told that: (1) they would make a series of investment decisions, (2) all individual investment decisions were anonymous to the group, and (3) they would be paid their individual earnings (privately and in cash) at the end of the experiment. Subjects then proceeded at their own pace through a set of instructions summarized below.[12]

> Subjects faced a series of decision rounds in which they were endowed with a specified number of tokens, which they invested between two markets. Market 1 was described as an investment opportunity in which each token yielded a fixed (constant) rate of output and that each unit of output yielded a fixed (constant) return. Market 2 (the CPR) was described as a market which yielded a rate of output per token dependent upon the total number of tokens invested by the entire group. The rate of output at each level of group investment was described in functional form as well as tabular form. Subjects were informed that they would receive a level of output from Market 2 that was equivalent to the percentage of total group tokens they invested. Further, subjects knew that each unit of output from Market 2 yielded a fixed (constant) rate of return.

Subjects knew with certainty the total number of decision makers in the group, their own endowment, the total number of tokens in the group, the productivity characteristics of the CPR, and the number of decision rounds in the current treatment condition. Individual token endowments were publicly known. After each round, subjects were shown a display that recorded their profits in each market for that round, total group investment in Market 2, and a tally of their cumulative profits for the experiment. During the experiment, subjects could request, through the computer, this information for all previous rounds for the current treatment condition. Subjects received no information regarding other subjects' *individual* investment decisions.

Parameters and Predictions

As seen above, our operationalization of the game is in the form of an investment decision between two "markets." Market 1 yields a constant and certain return per toked invested (w). Market 2 represents the CPR in that the return from this investment is dependent upon the overall level of group investment. We operationalized this environment with eight appropriators (n = 8) and quadratic production functions $F(\Sigma x_i)$ for Market 2, where:

$$F(\Sigma x_i) = a\Sigma x_i - b(\Sigma x_i)^2 \qquad (6)$$

with $F'(0) = a > w$ and $F'(ne) = a - 2bne < 0$.

For this quadratic specification, one has from (5) that the group optimal investment satisfies $\Sigma x_i = (a-w)/2b$. Further, the CPR yields 0% of optimal rents when investment is twice as large as optimal. The Nash equilibrium investments by large and small appropriators is given by:

$$\Sigma x_i = (M/(M+1))(a-w-bZ)/b,\ i=1,2,\ldots,M, \text{ and} \qquad (7)$$

$$\Sigma x_j = Z \equiv \Sigma e_j,\ j = M+1, M+2, \ldots, N.$$

These non-cooperative investment levels are between maximal net yield and zero net yield. The following constraints were placed on the choice of parameter values for a, b, c, d, e, and w in this study. First, to preserve equilibrium uniqueness, Nash equilibrium x_i and x_j must be integer valued, a constraint imposed by software design. Second, in order for heterogeneity in endowments to create a heterogeneous Nash equilibrium, the small players' endowments had to be sufficiently small to be a binding constraint in non-cooperative play.

The resulting parameter set is shown in Table 2. Each small player is endowed with 8 tokens per round, each large player with 24. Further, each player is charged an endowment fee of \$.02 per token per period to lower the cost of the experiments. This fee is a sunk cost, thus having no effect on Nash equilibrium or optimal investment levels.

These parameters lead to the following experimental conditions. First, there exists a unique Nash equilibrium where: (i) small endowment players each invest all 8 of their tokens in Market 2 (the CPR) and (ii) large endowment players each invest 16 tokens in Market 2 and 8 tokens in Market 1. At this equilibrium, small players receive a per-period payoff of (8 x \$.09) - (8 x (\$.02) = \$.56. Large players receive a per-period payoff of (8 x \$.05) + (16 x \$.09) - (24 x \$.02) = \$1.36. Group earnings are maximized by having 56 tokens invested in Market 2, yielding a group per period payoff of \$11.78. At the Nash equilibrium subjects earn approximately 49% of the *maximum rents* from the CPR.

These parameter values also generate meaningful differences in investment patterns and payoffs across different allocation rules (displayed in Table 2). Under the rule of *equal withdrawal*, each player invests 56/8 = 7 tokens at the group optimum. Each small player receives a net payoff of \$1.23, while each large player receives a net payoff of \$1.70. Using the noncooperative Nash appropriation level as the reference point, *equal absolute reductions* in tokens invested in Market 2 requires each player to remove 40/8 = 5 tokens from Market 2. Each small player invests 3 tokens in Market 2, with a net payoff of \$.66. Each large player invests 11 tokens in Market 2, with a net payoff of \$2.26. (Note that small players are still better off with this convention relative to the Nash equilibrium). Again using the Nash equilibrium as the reference point, an *equal proportionate reduction* in tokens invested in Market 2 requires the group to cut token investment in Market 2 by 41.67%. Each small player invests 5 tokens in Market 2, with a net payoff of \$0.94. Each large player invests 9 tokens in Market 2, with a net payoff of \$1.98. It is important to stress that payoff differences across allocation rules would vanish if resource endowments to the appropriators were identical.

Treatment Sequences

Subjects participated in two (consecutive) ten round sequences of the asymmetric game.[13] In the first ten rounds subjects were not allowed to communicate. In the final ten rounds the subjects were informed that prior to each decision round they would have the opportunity to discuss the investment problem (10 minutes prior to the first investment round and 3 minutes prior to each subsequent round). No physical threats are side payments were allowed.[14] Thus, the structure of the experiment can be summarized as follows:

X,X,...,X,C-X,C-X,...,C-X.

Experimental research by Hoffman and Spitzer (1982, 1985) suggests that strategically irrelevant differences in the method for allocating preferred subject types in experiments can have a significant effect on behavior. In their 1982 experiments, matched subject pairs bargained over the split of $14. Before bargaining began, one person was chosen at random to be the "controller"; if the bargainers could not agree on a split, the controller would receive $12 of the $14, and the other bargainer would receive $2. They found that all 12 bargaining pairs agreed to split the $14 evenly, which can be interpreted as a failure of self-regarding behavior on the part of the controller. In their 1985 experiments the controller "earned" the position in a contest; only 4 of the 22 bargaining pairs in this new experimental setting split evenly, and on average the controller received $12.52. This type of allocation effect may be relevant to the behavior of large and small endowment appropriators in this CPR study. As a consequence, we employed two mechanisms for allocating endowment positions -- one a random allocation, the other an auction market allocation.

With the first allocation mechanism, large endowment positions were allocated randomly prior to the ten decision rounds without communication, and again prior to the ten decision rounds with communication. The instructions for this randomization process are summarized below. Subjects were informed that:

> For each of the next 10 rounds one-half would be allocated 8 tokens, while the other half would be allocated 24 tokens. Tokens would be randomly allocated in such a way that each was equally likely to have 8 or 24 tokens.

The actual randomization process required one subject to "blindly" draw 4 slips of paper from a hat. The four subjects whose identification number was chosen (and noted publicly) received the endowment of 24 tokens.

A multiple unit second price auction was used as the alternative mechanism for assigning property rights to endowment positions. Prior to the ten decision rounds with no-communication and again prior to the ten decision rounds with communication the subjects received a set of instructions summarized below. The subjects were informed that:

> For each of the next 10 rounds one-half would be allocated 8 tokens, while the other half would each be allocated 24. Tokens would be allocated using an <u>auction</u> in which each subject bid for the right to have 24 tokens. The auction began with each subject raising their right hand. The auctioneer called out bids that increased every 5 seconds, in $.25 intervals. When the auctioneer reached a bid that was the highest total amount a subject was willing to pay to have 24 tokens rather than 8 tokens each round, the subject should lower their hand. This meant the subject was out of the auction. When there were only 4 persons left with their hands raised the auction stopped. Each of the 4 persons remaining in the auction were allocated 24 tokens each round for the next 10 rounds, paying a one time auction price equal to the last bid that was called by the auctioneer when the auction stopped. The 4 persons who dropped out of the bidding process were allocated 8 tokens each round.

III. EXPERIMENTAL RESULTS

Overview

In this section we present an overview of the results from our four design cells: (1) No-Communication-Random Token Allocation (NC-R), (2) Communication-Random Token Allocation (C-R), (3) No-Communication-Auction Token Allocation (NC-A), and (4) Communication-Auction Token Allocation (C-A). The discussion focuses first on individual investments in the CPR (Market 2), followed by a summary of rent accrual as a percentage of optimum.[15] This overview of results will be followed by a discussion of: (a) agreements to specific allocation rules and adherence to these agreements, and (b) auction prices.

Individual Decisions

Figure 1 displays frequency distributions of individual Market 2 decisions for each of the design cells. Several summary points are of interest. First, note the similarity in decisions for both design conditions with no-communication (the left hand panels). Individual decisions are dispersed across the feasible token investments with a modal investment of 8 tokens. Recall that low token endowment subjects had an allocation of 8 tokens. The high frequency at 8 can be attributed primarily to those subjects investing their entire endowments in the CPR in numerous decision rounds (consistent with the Nash prediction). Focusing on specific decision rounds, however, we do not observe a pattern of investments (at the individual level) consistent with the Nash prediction of 8 tokens for low endowment subjects and 16 tokens for high endowment subjects. This latter result is consistent with previously reported results for this decision environment (Walker, Gardner, and Ostrom 1990).

The opportunity to communicate led to a noticeable change in the pattern of Market 2 investments. With the appropriation rules agreed upon in communication rounds (discussed in more detail below), subjects concentrated their Market 2 investments near the optimal allocation of 56 tokens aggregate. In the treatment condition C-R (upper right hand panel), individual Market 2 investments of 8 tokens represents the modal response (67%). In the C-A condition, however, we observe a spread of investments clustered in the range of 6-10 tokens. The explanation for this behavior will be made clear from the discussion of communication agreements presented below.

Rents

In the treatment conditions in which tokens were allocated randomly, rents could be dissipated through overinvestment in Market 2, the CPR. In the auction treatment conditions, rents could be dissipated further by the competition for appropriation capacity. For now, we focus on rent dissipation from overinvestment in the CPR, and turn to rent dissipation from the auctions in a later section. Table 3 displays summary information regarding the level of rents generated across the 4 design conditions. For both treatment conditions with no-communication, we observe a level of rent accrual relatively close to that predicted by the Nash equilibrium (48.9%). In condition NC-R, the overall mean rent is 45.3% of optimum and for NC-A the level is 45.8%. The opportunity to communicate leads to a noticeable shift toward optimality. In condition C-R, overall rents increase to an average of 93.6%, and for C-A the level is 96.1%.[16] Thus, even in an environment of extreme heterogeneity in subject endowments, communication remains a powerful mechanism for promoting coordination.

Allocation Rules and Defections

Allocation Rules: Summary

Table 4 displays a summary of the allocation rules devised under the conditions of random token allocation and auction token allocation. Shown are the frequencies with which each of the allocation rules were proposed or agreed upon. Although there appear to be a rather diverse set of rules which were actually agreed to, a high percentage of these agreements can be summarized along a few simple principles. In all 8 experiments, the endogenously agreed upon allocation rules were devised under conditions where:

> Subjects: (1) sought to maximize group returns, and (2) perceived an aggregate allocation of 64 tokens as the optimum.[17]

In actuality, an investment of 64 tokens yields rents that are 98% of optimum.[18]

The rules adopted for allocating token investments across group members varied between the random and auction designs.[19] In the random design, subjects agreed upon rules in 32 of 40 decision rounds. These rules can be principally organized around two distribution concepts: (1) equal CPR appropriation, and (2) marginal reductions in payoff differentials by having small appropriators invest marginally more tokens in the CPR than large appropriators. In particular, of the 32 agreements, 18 specified equal CPR appropriation and 12 specified marginal reductions in payoff differentials.

In all experiments in the auction design, subjects adopted allocation rules that explicitly attempted to equalize net payoffs (net of auction price), while achieving close to optimal investment in Market 2. In 36 of the 40 decision rounds, this resulted in subjects choosing allocation rules that allowed large appropriators to invest more in the CPR than the small appropriators. Below we present a few representative comments which illustrate the nature of the discussion process:

"We have to decide which is the best number...I think the best number is 64 ...."

"Obviously we want to maximize our group return, right?... that's at 64."

"We need to allow the people who bid for the 24 to make up their bid price."

Defections

The occurrence of obvious defections on agreed-upon allocation schemes is relatively minor across the set of 8 experiments. Agreements were reached in 72 of 80 decision rounds. In total, we observed 21 of 72 decision rounds (37 of 576 individual decisions) in which at least one subject was observed to have defected. However, in all but three instances, the magnitude of the defectors' investment in Market 2 was no more than 4 tokens above the agreement. Further, defection led to a breakdown of subjects' ability to adopt agreements in only one experiment. In experiment 2 of the C-R design, there was a round 1 defection of 16 tokens by one subject and 8 tokens by another. Following this defection, this group successfully reached agreement in only one of the 9 remaining decision rounds. Thus, in 7 of 8 experiments, subjects were able to devise agreements, and maintain commitment to those agreements, over numerous decision rounds.

Auction Prices: NC-A and C-A Conditions

Price Levels

Using noncooperative game theory as a benchmark for auction prices, the auction we employed should yield reservation prices consistent with individuals' expectations of the value of having 24 tokens rather than 8. One possible source of these expectations is the value of the 16 additional tokens at the Nash equilibrium in the CPR game. The expected payoff for subjects with the small endowment is \$.56 per round and for large endowment is \$1.36, a difference of \$.80 per round. Because auction winners were endowed with an additional 16 tokens in each of 10 rounds, this leads to a prediction of \$8.00 as the auction price.

As displayed in Table 5, auction prices were similar across the eight auctions we conducted. The four NC-A auctions generated prices of: (1) \$5.25, (2) \$7.75, (3) \$9.50, and (4) \$8.25 for an average of \$7.69. The four C-A auctions generated prices of: (1) \$8.00, (2) \$7.25, (3) \$9.75, and (4) \$7.00 for an average price of \$8.00. Clearly, the auction prices are broadly consistent with Nash expectations. On the other hand, this does not rule out the possibility that they are consistent with other expectations. For example, in the C-A condition, one might conjecture that subjects may be forward looking in the sense that they anticipate group cooperation with an investment in Market 2 of 64 tokens (the level of Market 2 investments that they seem to perceive to maximize earnings). This conjecture yields a wide range of possible payoffs - \$4.80 to \$24.00 - depending upon the distribution of tokens one anticipates for investments in Market 2.[20]

Effects on Net Earnings

The fundamental behavioral question of this study concerns rent dissipation - with and without communication. At the individual level, the auction dissipated the added gains that could be earned from being a large appropriator. This occurred both in the communication condition, in which subjects explicitly tailored allocation rules to equalize payoffs net of auction prices, and in the no-communication condition, where such agreements were not possible. Consider the average net payoff for large appropriators relative to small. In all 4 replications under the C-A condition and 3 of 4 replications under the NC-A condition, this difference was negative, but averaged less than 10 cents per round. The exception was the first replication under the NC-A condition, in which large appropriators made an average of 51 cents per round more than small appropriators.[21]

At the group level, competition in the auction for appropriation resources led to a significant loss in rents. This point is illustrated in Table 5. For each of the 8 auctions, Table 5 displays the auction price (paid by each of 4 bidders) and the effect on potential earnings. Specifically, for each condition we report actual earnings (net of auction prices) as a percentage of maximum possible earnings. These results point to significant losses in rents through competition for appropriation capacity and through overinvestment in the CPR. Thus, under the NC-A condition we observed rent dissipation at two levels: (1) competition for appropriation capacity, that is, acquiring a large endowment of tokens, and (2) overinvestment in Market 2, the CPR. Under the C-A condition rent dissipation occurred primarily through competition for appropriation resources, since subjects used communication to overcome overinvestment in the CPR.

V. NEW DESIGN: COMMUNICATION IN A MORE "COMPLEX" SETTING

Theory and Experimental Design

One of the regularities observed in the experimental data is the extensive use of allocation rules that either specified equal appropriation from the CPR (primarily the C-R experiments), or were tailored to minimize net payoff differences (primarily the C-A experiments). These results stand in contrast to the predominant role of proportionate allocation rules observed in our field sample, as described in section II above. One possible argument for this disparity is that field settings are complex relative to the laboratory. Proportionate allocation rules may be a "rule-of-thumb" response to complexity. In the experiments, there were only two types of appropriators. Moreover, an individual's type and payoff function is common knowledge. This complete information setting allows for rules to be a function of relative payoffs. These conditions may not capture important complexities of many field settings. For example, Wiggins and Libecap (1985) find substantial evidence that heterogeneity and asymmetric information significantly increases the difficulties involved in using communication to resolve commons dilemmas in oil fields. This basic result is also observed in the oil field unitization bargaining experiments of Wiggins, Hackett, and Battalio (1991).

These issues led us to develop a more complex laboratory decision environment. In this environment there are four endowment classes – 8, 12, 20, and 24 tokens – with two appropriators in each class. Moreover, information on each individual's token endowment is incomplete and asymmetric; individuals knew their own endowment, and knew that the total tokens held by the group was 128. They did not know the individual endowments of other subjects.[22] Tokens were randomly allocated at the beginning of an experimental session. Subjects maintained their endowment type for the entire experiment. This procedure avoided subjects being able to deduce other endowment types from their own past experiences. As before, ten rounds of the CPR game with no-communication were followed by ten rounds with communication.[23]

For experimental control, the CPR production function was not changed for this design. The idea was to hold the production function constant and observe the effect of a more "complex" environment in which more subject types exist, and in which subjects may not be able to credibly communicate their endowment to others. Solving in a manner similar to that in equation (7) above, the Nash equilibrium requires the 8-token and the 12-token players to invest their full endowment in Market 2, while the 20-token and the 24-token players invest 14.4. Since tokens in the experiment are not divisible, this Nash equilibrium is not unique; the two large-endowment types will mix between 14 and 15. Note, however, that this design maintains heterogeneity in CPR appropriation at the Nash equilibrium, an important characteristic of our initial design.

Results

Three experiments using this design were conducted. Summary information on rents as a percentage of optimum is reported in Table 6. Means are calculated on data pooled from the first five and the last five decision rounds of a given treatment condition for each of the three experiments. The complexity of incomplete and asymmetric information on individual endowment holdings appears to have lowered the rent-enhancing properties of communication, although rents are increased relative to no-communication conditions. Compare rents in the communication condition of this more complex design (where tokens are allocated randomly) with rents generated in condition C-R of our initial design, as summarized in Table 3. In 3 of 4 experiments in the C-R condition, mean rents were higher than in any of the more complex experiments. Further, if data are aggregated by condition rather than by experiment, overall mean rents in the more complex design are 83.4% relative to 93.6% in the C-R condition.

Further evidence of the difficulties caused by this more complex environment is the frequency of failures to reach group-wide agreement on an allocation rule in communication rounds. Of the 80 communication rounds in the *initial* experiments, only 8 ended without group-wide agreement on an allocation rule, and all of these occurred in experiment 2 of the C-R design (an overall 10% failure rate for agreements). Moreover, only 37 of the 576 individual investment decisions in the rounds with agreements exceeded the agreement (a 6.4% defection rate on agreements). In contrast, in the 30 communication rounds in the new more complex design, 9 ended without group-wide agreement on an allocation rule (a 30% failure rate).[24] Even when these groups reached agreement, the rate of defection was higher. 27 of the 210 individual investment decisions in these rounds with agreements exceeded the agreement (a 12.9% defection rate). Thus the failure rate for agreements tripled, and the rate of defections on agreements approximately doubled.

Rule choice in these experiments differed in some interesting ways from those observed in the previous designs. In the first experiment the only adopted allocation rule was equal CPR appropriation -- each invest 8 tokens in Market 2. In the second experiment, however, we see the first implementation of a proportionate rule; subjects agreed to invest one-half of their token endowment in Market 2. Substantial defections led to the breakdown of this agreement. The subjects later agreed to a more complex rotation scheme in which one group of subjects would invest all in Market 2, and the others invest no tokens in Market 2. In the third experiment, the first agreement was equal CPR withdrawal -- each invest 6 tokens in Market 2. This rule was modified to allow several subjects to invest more in Market 2, and later changed to a modified proportionate rule in which all subjects with more than 8 tokens invested one-half of their endowment in Market 2. It is interesting to note that this more complex design results in a higher frequency of proportionate rules implemented by the subjects. This finding lends support to our original notion that proportionate allocation rules are a "rule-of-thumb" response to complex decision environments.

VI. CONCLUDING COMMENTS

Past experimental studies have demonstrated the efficacy of face-to-face communication as an institution to foster increases in efficiency in collective action situations. The results from this study demonstrate the robustness of this institution in situations of endowment heterogeneity. Heterogeneous appropriators, when allowed to engage in face-to-face communication, substantially increase the level of rents earned from the common pool resource. In addition, rent enhancement remains substantial (although reduced) under relatively severe conditions of four endowment types with incomplete and asymmetric information.

In 7 of 8 experiments of our first two design conditions, subjects chose and successfully maintained allocation rules which were consistent with approximate rent maximization. In our treatment design in which token endowments were allocated randomly, subjects most frequently adopted rules which called for equal withdrawal. In our treatment design in which larger token endowments were purchased through an auction mechanism, subjects explicitly sought to adopt rules to achieve maximum rents and equalize payoffs net of auction prices.

In field CPR settings, we observe a substantial percentage of agreements in which appropriators agree to proportionate reductions in levels of appropriation. Rarely did we observe the proposal of and agreement upon such rules in our initial designs. In the more complex design, in which there were four endowment types with incomplete and asymmetric information, subjects agreed to forms of proportionate rules in two of three experiments. In particular, subjects in the second experiment began with a proportionate rule, but substantial defections led to the breakdown of this agreement. In the third experiment, subjects began with an equal withdrawal rule and later switched to a proportionate rule. In all three experiments in this design, communication was efficiency enhancing, but maintaining rule choices was more problematic.

It is the results from these latter experiments which point most directly to why one may observe institutions in the field which nest face-to-face communication with mechanisms which allow for the sanctioning of nonconforming behavior. Face-to-face communication is a powerful tool. It is handicapped significantly, however, in situations in which group members are unable to develop or sustain the social capital necessary for enduring commitments. Understanding further the origin and success of alternative rule mechanisms is important to understanding how appropriators can develop self governing institutions. It is a topic for our continued research.

ENDNOTES

1. Fishers sharing inshore fishing grounds in Turkey (Berkes 1986a), in Brazil (Cordell and McKean 1986), in Japan (Ruddle and Akimichi 1984), in Eastern Canada (Davis 1984) and Western Canada (Marchak, Guppy, and McMullan 1987) have all devised various rules to restrict entry and allocate access and appropriation rights so as to avoid CPR dilemmas. Groundwater pumpers in seven Southern California groundwater basins have devised complex rules to regulate appropriators so as to reduce conflict and avoid the mining of their groundwater basins (Blomquist 1992). See Ostrom (1990) for further examples.

2. Whether the social dilemma games are 2-person or n-person (Orbell, et.al. 1988), single play (Bornstein and Rapaport 1988) or repeated play (Liebrand 1984), time independent (Ostrom and Walker, 1991, Isaac and Walker, 1991), or time dependent (Brechner 1977), individuals who are permitted to communicate achieve superior outcomes compared to those who are not permitted to communicate.

3. These issues have recently been investigated in a theoretical context by Hackett (1992). His work suggests that heterogeneous resource endowments can lead to disagreement over the supply and implementation of rules that allocate access to CPRs. For example, consider the two allocation rules found in the field CPR cases we survey in section II -- equal appropriation and appropriation proportionate with capacity or historic use. The interests of large endowment appropriators are served by proportionate allocations, while the interests of small endowment appropriators are better served by equal-sized appropriation rights allocations. When self-governing CPR groups are heterogeneous, rule supply involves a tradeoff between the cost of investing in the "social capital" necessary to reach consensus on an allocation rule, and the added costs of monitoring and enforcing agreements opposed by some subset of appropriators.

4. The primary source for the case studies in Table 1 was Fenton Martin (1989) *Common Pool Resources and Collective Action: A Bibliography*. Bloomington, IN: Indiana University, Workshop in Political Theory and Policy Analysis. The cases in Table 1 do not represent an exhaustive survey of all case studies in Martin (1989). From a set of cases with well-documented allocation rules, this particular subset was chosen to illustrate the variety of rules found in the field.

5. We rely significantly on the discussion in Ostrom, Walker, and Gardner (1992) for our description of the game environment.

6. One can interpret this environment as a limited access CPR (see, for example, Clark 1980; Cornes and Sandler 1986; and Negri 1989).

7. If overall investment is held constant, one token invested in Market 2 yields the same return regardless of the identity of the player making the investment. Thus heterogeneity is in endowments, not in appropriation skills.

8. The Nash equilibrium can be made symmetric even with large and small endowment appropriators. In particular, a symmetric Nash equilibrium results as long as the small endowment level is greater than or equal to that required for equilibrium play. In such a case small endowment appropriators simply have a lower investment level in the outside market relative to large endowment appropriators.

9. Typically, the repeated game has many equilibria. Two equilibrium refinement principles are subgame perfection and subgame consistency. An equilibrium is subgame perfect if it prescribes equilibrium play on every subgame. An equilibrium is subgame consistent if it prescribes identical play on identical subgames.

10. During recruitment, subjects are told they will participate in a 1-2 hour decision-making experiment. The endpoint of each treatment sequence of the experiment was told to subjects at the beginning.

11. When the game X has a unique equilibrium x^*, neither finite repetition nor communication creates new equilibrium outcomes. Let c denote a communication strategy, in the communication phase C, available to any player. As long as saying one thing and doing another has no payoff consequences, then any strategy of the form (c,x^*) is an equilibrium of the one-shot game (C,X), and finitely repeated x^* is a subgame perfect equilibrium outcome of repeated communication (C,X,C,X,...,C,X). In this situation, subgame perfection is independent of communication.

12. A copy of the instruction is available from the authors upon request.

13. After completing the instructions, subjects had the opportunity to participate in a series of 5 salient reward decision with a symmetric game. Subjects in these initial rounds were endowed with 20 tokens each. Otherwise the parameters were identical to those in Table 1. These "trainer" rounds were implemented to give the subjects initial experiences with the logistics of the experiment.

14. Each person was identified with a badge. This facilitated player identification in our transcripts. If unanimous, players could forego discussion.

15. Thus our discussion of rents will be based on actual rents earned from Market 2 as a percentage of rents that would be earned if the group made the optimal investment of 56 tokens in Market 2. Note, the outside opportunity cost of a token invested in Market 2 is the return in Market 1 ($.05).

16. Comparing rents for NC-R vs C-R, NC-A vs C-A, and pooling within no-communication and communication conditions: (1) an hypothesis of no difference in means between no-communication and communication is rejected ($\alpha=.05$ level, t-test) and (2) an hypothesis that the samples are drawn from the same underlying distribution is rejected ($\alpha=.05$ level, Wilcoxon nonparametric test).

17. Evidence supporting this conclusion is found in transcripts of the communication rounds.

18. Why 64? The summary table subjects received for payoff returns from Market 2 shows possible levels of Market 2 investments (and resulting total, average, and marginal returns) for investment level beginning at 6 tokens and ending with 128 - with investment intervals of 6 or 7 tokens. 64 tokens is the level of investment shown on the table to maximize group returns from Market 2. Thus, as observed in many experiments, subjects tended to ignore marginal returns and focuses on a total return instead.

19. Adopted allocation rules led to different patterns of investments across the random and auction designs. In the random design, small appropriators were more likely to invest fewer tokens in Market 2 than in the auction design. The reverse holds for large appropriators. In both cases: (1) an hypothesis of no difference in means is rejected ($\alpha=.05$ level, t-test) and (2) an hypothesis that the samples are drawn from the same underlying distribution is rejected ($\alpha=.05$ level, Wilcoxon nonparametric test).

20. Alternatively, one might conjecture that observed auction prices are correlated more closely with the level of earnings subjects observed in prior treatment conditions. For instance, subjects might base their reservation price for bidding in the auction on average payoff per token calculated from prior experience. There is some support for this conjecture in our C-A design, but not in our C-R design.

21. In replications 1, 2, 3, and 4 of the NC-A condition, the average net payoff difference of large relative to small was \$.51, -\$.05, -\$.10, and -\$.01 per round. For the C-A condition, the differences were -\$.09, -\$.05, -\$.03, and -\$.04.

22. A token allocation was written on each of 8 slips of paper in a hat. Each subject blindly picked a slip of paper denoting their token allocation for each decision round of the experiment.

23. As with earlier designs, experiments began with 5 preliminary rounds in which each subject was endowed with 20 tokens.

24. Even this number is conservative because some of the "agreements" were very loose and informal, and only specified a range of token investment levels for each individual.

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FIGURE 1
INDIVIDUAL INVESTMENTS - MARKET 2
FREQUENCIES ACROSS DESIGN CONDITIONS

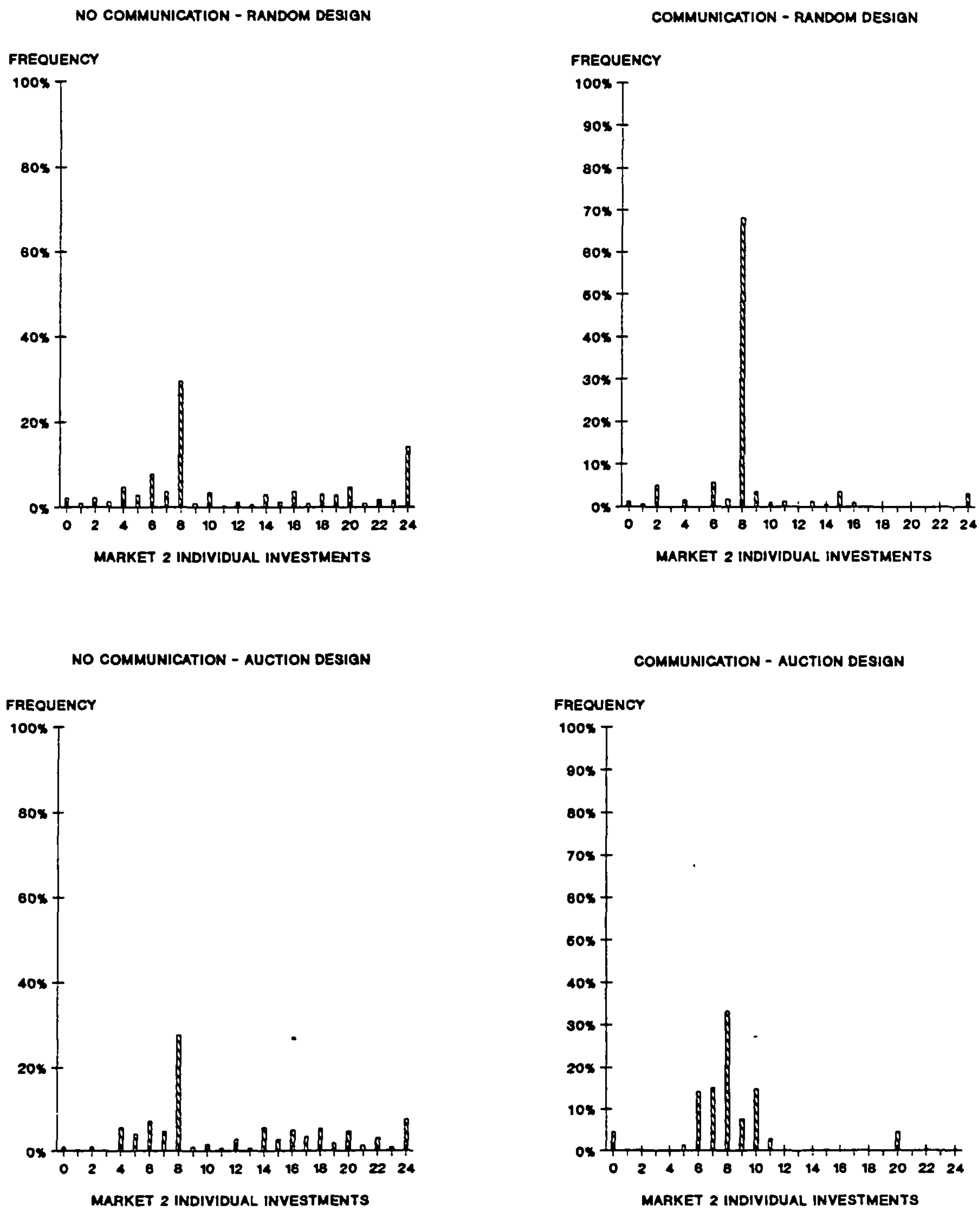

Table 1. Description of Case Studies

CPR TYPE	LOCATION	ALLOCATION RULES	DOCUMENTATION
Irrigation	Philippines	Proportional	Bacdayan (1980)
Irrigation	South and East Asia	Proportional	Bottrall (1978, 1981)
Irrigation	Philippines	Proportional	Coward (1979)
Irrigation	Philippines	Proportional	de los Reyes (1980)
Irrigation	Mexico	Proportional	Enge and Whiteford (1989)
Irrigation	Spain	Proportional	Glick (1970), Maas and Anderson (1978)
Irrigation	Sri Lanka	Proportional	Leach (1961)
Irrigation	Switzerland	Proportional	Netting (1981)
Irrigation	Iraq	Proportional	Spooner (1971, 1972, 1974)
Irrigation	India	Proportional	Wade (1988)
Irrigation	India	Equal withdrawal	Seckler and Joshi (1982)
Irrigation	Africa	Equal withdrawal	Gray (1963)
Groundwater Aquifers	U.S.A.	Proportionate reduction	Blomquist (1987, 1988, 1989, 1990)
Grazing Lands	England	Proportional	Slater (1907), Ault (1972)
Grazing Lands	Switzerland	Proportional	Netting (1981)
Oil Pools	U.S.A.	Proportionate reduction	McDonald (1971)
Fisheries	Australia	Equal withdrawal	Sturgess, et.al. (1982)
Fisheries	Canada	Proportionate reduction and equal withdrawal	Berkes and Pocock (1987)

Table 2. Experimental Design Baseline:
Parameters for a Given Decision Period

Subject Type:	LOW ENDOWMENT	HIGH ENDOWMENT
Number of Subjects	4	4
Individual Token Endowment	8	24
Production Function: Mkt.2*	$33(\Sigma x_k)-.25(\Sigma x_k)^2$	$33(\Sigma x_k)-.25(\Sigma x_k)^2$
Market 2 Return/unit of output	\$.01	\$.01
Market 1 Return/unit of output	\$.05	\$.05
Earnings per Subject at Group Maximum: Evaluated at Benchmark Conventions		
Equal withdrawal:	\$1.23	\$1.70
Equal absolute reduction:	\$0.66	\$2.26
Equal proprotionate reduction:	\$0.94	\$1.98
Earnings/Subject at Nash Equil.	\$0.56	\$1.33
Earnings/Subj. at Zero Net Yield	\$0.24	\$0.72

* Σx_k = the total number of tokens invested by the group in Market 2. The production function shows the number of units of output produced in Market 2 for each level of tokens invested in Market 2. All payoffs include a per period fee of \$.02 per token.

Table 3. Rents as a Percentage of Optimum

Design: Random Allocation of Tokens				
	No communication		Communication	
Experiment	1-5	6-10	1-5	6-10
1	31.4	37.9	97.5	99.9
2	55.8	24.5	80.4	81.1
3	52.9	41.8	97.5	97.0
4	61.5	56.5	96.6	98.4

Design: Auction Allocation of Tokens				
	No communication		Communication	
Experiment	1-5	6-10	1-5	6-10
1	61.0	54.1	90.7	90.2
2	31.2	29.0	97.5	97.9
3	58.3	68.1	98.0	97.5
4	34.3	30.4	97.3	99.5

Table 4. Summary Frequency of Allocation Rules: Investments in Market 2

	RANDOM		AUCTION	
	PROPOSED	AGREED	PROPOSED	AGREED
50% of Endowment	1	0	1	0
Large: 66% Endowment Small: 33% Endowment	1	0	0	0
Equal Absolute Reduction	0	0	1	0
Large=6 Small=8	4	4	0	0
Large=7 Small=8	1	1	0	0
Large=7.5 Small=8 *	7	7	0	0
Large=8 Small=7	0	0	7	7
Large=8 Small=8	19	18	9	4
Large=8.5 Small=8 *	0	0	2	2
Large=9 Small=7	0	0	6	5
Large=9 Small=8	2	1	0	0
Large=10 Small=5	0	0	1	1
Large=10 Small=6	0	0	10	10
Large=10 Small=7	0	0	1	0
Large=10 Small=8	0	0	9	9
Large=11 Small=6	0	0	1	1
Large=11 Small=7	0	0	1	0
Large=11 Small=8	0	0	1	1
Large=12 Small=8	1	1	0	0

* Subjects agreed to a rotation scheme of 7-8 or 8-9.

Table 5. Auction Prices: Effects on Potential Earnings

NO-COMMUNICATION		COMMUNICATION	
AUCTION PRICE	EARNINGS AS A % of OPTIMUM	AUCTION PRICE	EARNINGS AS A % OF OPTIMUM
$5.25	52.6%	$8.00	66.3%
$7.75	26.5%	$7.25	73.7%
$9.50	42.8%	$9.75	65.1%
$8.25	26.4%	$7.00	75.0%

Table 6. New Design: Rents as a Percentage of Optimum

Design: Random Allocation of Tokens				
	No communication		Communication	
Experiment	1-5	6-10	1-5	6-10
1	44.2	28.7	90.3	81.7
2	49.0	47.9	83.7	83.3
3	77.5	51.7	86.1	75.2