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**Social Capital and Cooperation:
Communication, Bounded Rationality, and Behavioral Heuristics**

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ABSTRACT

Common-pool resources are natural or man made resources used in common by multiple users, where yield is subtractable (rival) and exclusion is nontrivial (but not necessarily impossible). The role of face-to-face communication in CPR situations, where individuals must repeatedly decide on the number of resource units to withdraw from a common-pool, is open to considerable theoretical and policy debate. In this paper, we summarize the findings from a series of experiments in which we operationalize face-to-face communication (without the presence of external enforcement). In an attempt to understand the high degree of cooperation observed in the laboratory, we turn to a bounded rationality explanation as a starting point for understanding how cooperative behavior can be supported in decision environments where game theory suggests it will not.

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Introduction: The Communication Mechanism

Common-pool resources (CPRs) are natural or man made resources used in common by multiple users, where yield is subtractable (rival) and exclusion is nontrivial (but not necessarily impossible). Examples of CPR situations include fisheries, commonly held forrest areas, and university computing systems. Individuals using such resources are generally assumed to face a social dilemma, where over use and possible destruction is a predicted outcome. The ameliorative role of face-to-face communication in common-pool resource situations, where individuals must repeatedly decide on the number of resource units to withdraw from a common-pool, is open to considerable theoretical and policy debate. Words alone are viewed by many as frail constraints when individuals make private, repetitive decisions between short-term, profit maximizing strategies and strategies negotiated by a verbal agreement. On the other hand, the "shadow of the future" may reduce the temptation to break promises so as to avoid the "unraveling" of a mutually productive verbal agreement (see Keohane 1986).

Game-theoretical models do not always yield unique answers to how individuals will (or ought to) behave in repeated, social dilemma situations. Such games can have multiple equilibria, even if the one-shot game has a unique equilibrium. The number of equilibria grows with the number of repetitions. When there are finitely many repetitions, no equilibrium can sustain an optimal solution although it may be possible to come close (Benoit and Krishna 1985). When there are infinitely many repetitions, some equilibria can sustain an optimal solution (Friedman 1990). In all cases, the worst possible one-shot equilibrium, repeated as often as possible, remains an equilibrium outcome. The players thus face a plethora of equilibria. Without a mechanism for selection among these equilibria, the players can easily be overwhelmed by complexity and confusion.

There is also a debate within the literature about the necessity of external enforcement. Some theorists presume that stable and efficient equilibria can be achieved by participants in repetitive situations without the necessity of external enforcers (Schotter 1980; Runge 1984). This argument is based primarily on the efficacy of trigger strategies. On the other hand, many assume that individuals in repetitive CPR situations will not reach jointly efficient outcomes unless external agents monitor and enforce agreements. Even if individuals promise to adopt strategies that generate the highest joint outcome, promises are considered worthless when individuals face a series of private decisions without individual monitoring and enforcement. Why should a person keep a general promise made to a group when the short-term payoff from breaking that promise is substantially better, especially if no one knows the identity of those who break their promise? A deeper examination of the role of communication in facilitating the selection of efficient strategies is of considerable theoretical (as well as policy) interest.[1] The demarcation line between cooperative and noncooperative game theory is based on the presumption that communication alone does not affect players' decisions unless there is external enforcement or some other form of making agreements binding.

In prior laboratory investigations, communication has been shown to be a very affective mechanism for increasing the frequency with which players choose joint income maximizing strategies, even when individual incentives conflict with the cooperative strategies (Caldwell 1976; Dawes, McTavish, and Shaklee 1977; Edney and Harper 1978; van de Kragt et al. 1986, Isaac and Walker 1988a and 1991; Jerdee and Rosen 1974; Orbell, van de Kragt, and Dawes 1991; E. Ostrom and Walker 1991; E. Ostrom, Walker, and Gardner (1992), and Hackett, Schlager, and Walker 1992). Hypotheses forwarded to explain why communication increases the selection of cooperative strategies identify a process that communication is posited to facilitate: (1) offering and extracting promises, (2) changing the expectations of others' behavior, (3) changing payoff structure, (4) the reenforcement of prior normative orientations, and (5) the development of a group identity.

In this paper we summarize the findings from a series of experiments in which we operationalize face-to-face communication (without the presence of external enforcement) in an experimental CPR appropriation environment.[2] The role of communication and its success in fostering outcomes more in line with social optimality is investigated in settings in which: (1) the communication mechanism is provided as a costless one-shot opportunity, and (2) the communication mechanism is provided as a costless opportunity and on a repeated basis. After summarizing the findings from a series of experiments, we turn to a bounded rationality explanation as a starting point for understanding how cooperative behavior can be supported in decision environments where game theory suggests it will not. Specifically, we examine a notion of measure-for-measure behavior where subjects adhere to verbal commitments when others do, and react to defections in a measured response that allows for cooperation to be potentially sustained, even when some subjects are noncooperative. We first turn to a summary of the CPR decision environment in which our subjects participate.

The CPR Decision Situation

The decision task faced by our subjects can be summarized as follows:

Subjects faced a series of decision periods 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. 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.

The experiments used subjects drawn from the undergraduate population at Indiana University. Students were volunteers recruited primarily from principles of economics 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 situation" 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 at IU. The computer facilitates the accounting procedures involved in the experiment, enhances across experimental/subject control, 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 that described the decisions.[3] Subjects knew with certainty the total number of decision makers in the group, total group tokens, and that endowments were identical. After each round, subjects were shown a display that recorded: (a) their profits in each market for that round, (b) total group investment in Market 2, and (c) a tally of their cumulative profits for the experiment. During the experiment, subjects could request, through the computer, this information for all previous rounds. They knew that the experiment would not last more than two hours. They did not know the exact number of investment decision rounds. All subjects were *experienced*, i.e., had participated in at least one experiment using this form of decision situation.[4]

The theoretical specification of our CPR environment can be summarized as follows. Assume a fixed number n of appropriators with access to the CPR. Each appropriator i has an endowment of resources e 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 investment as a percentage of the aggregate. Let x_i denote appropriator i's investment in the CPR, where $0 \leq x_i \leq e$. 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 $F'(ne) < 0$. Initially, investment in the CPR pays better than the opportunity cost of the foregone safe investment [$F'(0) > w$], but if the appropriators invest a sufficiently large number of resources ($\hat{q}$) in the CPR the outcome is counterproductive [$F'(\hat{q}) < 0$]. The yield from the CPR reaches a *maximum net level* when individuals invest some but not all of their endowments in the CPR.[5]

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

$$u_i(x) = \begin{cases} we & \text{if } x_i = 0 \\ w(e-x_i) + (x_i/\Sigma x_i)F(\Sigma x_i) & \text{if } x_i > 0. \end{cases} \quad (1)$$

(1) reflects the fact that if appropriators invest all their endowments in the outside alternative, they get a sure payoff (we), whereas if they invest some of their endowments in the CPR, they get a sure payoff $w(e-x_i)$ plus a payoff from the CPR, which depends on the total investment in that resource $F(\Sigma x_i)$ multiplied by their share in the group investment $(x_i/\Sigma x_i)$.

Let the payoffs (1) be the payoff functions in a symmetric, noncooperative game. Since our experimental design is symmetric, there is a symmetric Nash equilibrium, with each player investing x_i^* in the CPR, where:

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

At the symmetric Nash equilibrium, group investment in the CPR is greater than optimal so group yield is less than optimal, but not all yield from the CPR is wasted.[6]

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),

$$u(x) = nwe - w\Sigma x_i + F(\Sigma x_i) \quad (3)$$

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

$$-w + F'(\Sigma x_i) = 0. \quad (4)$$

According to (4), the marginal return from a CPR should equal the opportunity cost of the outside alternative for the last unit invested in the CPR. The group payoff from using the marginal revenue = marginal cost rule (4) represents the maximal yield that can be extracted from the resource in a single period.

In our experimental investigation we have operationalized this CPR situation with eight appropriators ($n = 8$) and quadratic production functions $F(\Sigma x_i)$, where:

$$F(\Sigma x_i) = a\Sigma x_i - b(\Sigma x_i)^2 \tag{5}$$

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

In particular, we focus on experiments utilizing the parameters shown in Table 1. Subjects are endowed each period with either 10 tokens or 25 tokens depending upon design conditions. With the payoff parameters displayed in Table 1, a group investment of 36 tokens yields the optimal level of investment. This symmetric game has a unique Nash equilibrium with each subject investing 8 tokens in Market 2.

Much of our discussion of experimental results will focus on what we term "Maximum Net Yield" from the CPR. This measure captures the degree of optimal yield earned from the CPR. Specifically, net yield is the return from Market 2 minus the opportunity costs of tokens invested in Market 2 divided by the return from Market 2 at MR=MC minus the opportunity costs of tokens invested in Market 2. In our decision situation, opportunity costs equal the potential return that could have been earned by investing the tokens in Market 1. Note, for a given level of investment in the CPR, net yield is invariant to the level of subjects endowment.[7] Recall, even though the range for subject investment decisions is increased with an increase in subjects endowments, the equilibrium and optimal levels of investment are not altered. At the Nash equilibrium, subjects earn approximately 39% of maximum net yield from the CPR.

Summary Experimental Results

Repeated Communication

Our first communication design involves repeated communication with both 10 token and 25 token endowments. At the outset, the CPR game was repeated for 10 rounds. After round 10, the players read an announcement, informing them they would have an opportunity for discussion after *each* subsequent round. The instructions are given below.

> *Sometimes in previous experiments, participants have found it useful, when the opportunity arose, to communicate with one another. We are going to allow you this opportunity between periods. There will be some restrictions: 1) you are not allowed to discuss side payments, 2) you are not allowed to make physical threats, 3) you are not allowed to see the private information on anyone's monitor. Since there are still some restrictions on communication with one another, we will monitor your discussions between periods.*

The experimenter informed the subject that they would have up to 10 minutes for their first discussion period. Each subsequent discussion period would be no longer than 3 minutes. After the experimenter publicly reviewed this announcement, the players left their terminals and sat facing one another.[8]

The summary data for our experiments is reported as the average *percentage of maximum net yield* actually earned by subject groups. The summary data from the low-endowment 10 token series is reported in Table 2.[9] These repeated communication experiments provide strong evidence for the power of face-to-face communication. Players successfully used the opportunity to: (a) calculate coordinated yield-improving strategies, (b) devise verbal agreements to implement these strategies, and (c) deal with nonconforming players through verbal statements. Net yield averaged over 98% of optimum following the introduction of the opportunity to communicate. This degree of yield from the CPR is in contrast to an average of only 30% in pre-communication rounds. For analytical purposes we define a defection as a market 2 investment larger than agreed upon. In the low-endowment environment, we identified only 19 defections from agreements out of 368 total decisions (a 5% defection rate).

The high-endowment (25 token) CPR game is a more challenging decision environment. While the equilibrium prediction for 10 and 25 token endowment games is identical, the disequilibrium implications of the 25-token game change considerably. With 25 tokens, as few as three subjects investing all of their tokens can essentially ruin the CPR (bring returns below w), while with 10 tokens it takes seven out of eight subjects to accomplish this much damage. In this sense, the 25-token environment is much more *fragile* than the 10-token environment.

We were interested in exploring whether subjects could cope with this more delicate situation through communication alone. In the field this type of fragility is manifest in fisheries (all small boats versus all trawlers) and in forestry (individuals with chain saws versus bulldozers). Further, we were interested whether varying the information players received about past actions of all players and joint outcomes affected patterns of behavior. In the first three experiments of this design, subjects received only aggregate information on actions and outcomes between rounds. This level of information was identical to that of the 10 token repeated information discussed above. In last three experiments, subjects received additional information on individual market 2 investments. This information was by subject numbers only. Unless the subjects successfully used the discussion rounds to ascertain actual subject identity, this information treatment left subject identity anonymous.

Table 3 summarizes the data for the 25-token repeated communication experiments under both information conditions. In all six experiments, joint yield increased dramatically over that achieved in the first 10 rounds, averaging 71% of optimum in contrast to -2% in pre-communication rounds. Experiments 1, 3 and 5, however, demonstrate the fragile nature of nonbinding agreements in this high-endowment environment. In the high-endowment environment, we identified 100 defections from agreements out of 624 total decisions (a 16% defection rate).

One-Shot Communication

In this design we turn to examining the robustness of the communication mechanism. Subjects were given a one time opportunity (10 minutes) to communicate followed by a series of repeated (up to 22) independent decisions. This environment allows for several insights into the role of communication. Subjects have a one time opportunity to discuss the decision problem. They can work at determining a joint income maximizing strategy and agreeing to such a strategy. They have a one time opportunity to impress on each other the importance of cooperation. But since the communication mechanism is not repeated, they have no opportunity to react jointly to ex post behavior.

The transcripts of the discussion during the single communication round reveal that subjects perceived their problem as involving two tasks: (1) determining the maximal yield available and (2) agreeing upon a strategy to achieve that yield. Results from our three one-shot communication experiments are summarized in Table 4. The results are mixed. In experiment 1, the group achieved over 82% of maximum net yield in all but 2 of 22 rounds following communication. In experiment 2, communication had little efficiency-improving effects. Finally, in experiment 3, the group improved net yield significantly following communication, but could not sustain such behavior. Interestingly, the rate of defection on agreements in these 3 experiments jumps to 25% (132 defections out of 528 decisions).

Why So Much Cooperation in the Lab?

We are not the first to observe high levels of cooperation in experimental social dilemmas. The theory of infinitely repeated games is one explanation offered for this finding. In infinitely repeated games, one of the many possible equilibria is that of full cooperation based on the use of a trigger strategy (Friedman 1990). There are several reasons why we find unsatisfactory an explanation of cooperation in the laboratory CPRs that relies on the predictions from the theory of an infinitely repeated game in which grim trigger strategies are used to support the optimal solution. First, the situation individuals confront in the lab is explicitly finite.[10] More worrisome is that the most important behavior consistent with this explanation of cooperation are not observed. Specifically, if subjects were behaving as if the game were infinite and using grim strategies, we should observe: (1) no deviations from agreements (or, at most a very small number), or (2) all participants investing substantially more than their agreement in the CPR for the rest of the experiment, if (by error or some other problem) deviations did occur. Our observations are not consistent with either prediction. The defection rate was systematically related to the extent of communication. When subjects discussed strategies during communication rounds, they explicitly rejected anything like a grim trigger. "We'd only be screwing ourselves" was the usual reaction to such a proposal. We never observed grim trigger strategies played in the laboratory on any of the many occasions when subjects had the opportunity to use them. A small amount of chiseling on agreements rarely meant the rapid end of generally cooperative behavior. In those situations where individuals could discuss the problems of small defections, they were usually able to surmount this problem. Even when they could not discuss the problem, they often sustained close to optimal outcomes even though some individuals made investments at a somewhat higher level than that agreed upon.

Given this conclusion, at least two other theoretical directions could be taken. The first retains the hypothesis of completely rational play and posits that the subjects are involved in a much more complicated game of incomplete information.[11] A solution to this more complicated game might explain why one gets so much cooperation. We are reluctant to take the approach of incomplete information combined with complete rationality. Since our subjects have considerable difficulty in solving simple maximization problems such as the one-shot maximum, it is even more unlikely that they will solve the complex maximization problems involved in incomplete information games.[12] At the same time, subjects usually come within a few percent of an optimal solution in simple maximization problems. This is tantalizing evidence of bounded rationality. It is this second direction, bounded rationality, which we will take.[13]

If subjects frame the decisions they face differently from the way game theory frames them, this difference will have behavioral implications. For example, suppose the players approach the game as if it were repeated, but with only a vague notion of how many repetitions. Assuming a very low discount rate, they may realize there is more than one sensible way of playing the game and that there are group gains to some of these possibilities. Secondly, if subjects process the decisions differently from the way game theory posits their processing, this difference will again have behavioral implications. For instance, if players' responses are not game theoretic best responses, but have clear linkages to best responses, then their play may contain regularities reminiscent of game equilibrium. These are two principal features of the theory of bounded rationality as championed by Selten and his coworkers (Selten, Mitzkewitz, and Uhlich 1988) in duopolistic markets. Their results appear to apply to CPRs as well.

Game theory based on complete rationality requires that players have a strategy–a complete plan of play for every contingency. Selten and his coworkers argue that players plan only for likely contingencies. Such players are basically reactive in nature. Suppose that players in a communication phase have reached agreement on how play should proceed. As long as play proceeds according to the agreement, there is no need to react. Reaction is only called for when something unexpected happens, in particular, a defection from the agreement. One possible type of reaction is a *measure-for-measure reaction.*

Measure-for-Measure Reactions

In a measure-for-measure reaction, a player reacts mildly (if at all) to a small deviation from an agreement. The larger the deviation from an agreement, the larger the reaction. Thus, a measure-for-measure reaction is already different from a grim trigger strategy. The intuition behind measure-for-measure is that, by keeping play near the agreement, it is easier to begin a process (deliberation) on how to restore the agreement. Further, the risk of a complete unraveling toward the one-shot game equilibrium is reduced when players do not overreact to deviations. Since the payoff achieved from an agreement (or, play close to the agreement) dominates the one-shot game equilibrium, measure-for-measure play represents a practical response in the sense of bounded rationality.

Consider our designs with one-shot or repeated communication, where agents have agreed to contribute 6 tokens each to the CPR (this is the agreement reached in several of our experiments). Then a typical measure-for-measure reaction would look as shown in the top panel of Figure 1. Note the restrictive strategy space for measure-for-measure responses. The reaction shown in this figure has on the x-axis the average decision of all other players in the previous round (t-1), and on the y-axis the decision of a given player in the current round (t). The measure-for-measure reaction passes through the agreement: if all others kept to the agreement in t-1, then this player keeps to it in round (t). Moreover, if others invest less than the agreed amount, this player sticks to the agreement. Finally, if others invest more than the agreement calls for, this player responds in a measured fashion by investing somewhat more himself or by sticking to the agreement in the hopes of getting others to return to the agreement. Measured responses continue until the one-shot equilibrium is reached. At this point, no further responses are called for. Play has now reached the one-shot equilibrium, and any further deviations reduce a player's payoff. If play were to deteriorate beyond the Nash equilibrium, eventually a player would do best by leaving the CPR entirely and investing all tokens in the safe alternative.

The linear reaction shown in the top panel of Figure 1 is simple, but ignores the restriction that decisions have to be integer valued. We call any reaction function passing through the agreement point and the one-shot equilibrium, which is also nondecreasing in other players' decisions, a measure-for-measure reaction. The lower panel of Figure 1 graphically presents the measure-for-measure box, which shows the limits within which all such reactions must be found. Note that the lower left and upper right corners of this box are defined by the agreement reached in an experiment, AGREEMENT, and the Nash equilibrium point (8, 8), NASH. All integer-valued step functions lie within this box.

Besides measure-for-measure reactions, there are many alternative reactions subjects might exhibit in our decision situation. At one extreme, they may make the same decision under all circumstances, "constant play." We have observed behavior consistent with other possibilities as well. For instance, a subject who invests at a maximal rate while other subjects hold back their investment level to an agreed upon level, is playing "never give a sucker an even break." A variation on this strategy is observed when a subject convinces the others to invest at low levels, and then proceeds to invest at a maximal level themselves. This could be called "sand-bagging the suckers."

Measure-for-measure reactions appear to have improved cooperation in our communication experiments without sanctioning. Above, we summarized 13 experiments where subjects had at least one opportunity to communicate. In all these experiments, the anonymity of the subjects was maintained. In some of these experiments (all 25-token, one-shot communication and half of all 25-token repeated communication), subjects had information (although anonymous) about the individual investments of each player. An analysis of the responses made by subjects in these experiments is summarized below. For expositional purposes, we begin our discussion of "as if" measure-for-measure behavior with the experiments from our one-shot communication designs. In these experiments, subjects had a single opportunity to devise and agree to a strategy and then to react to each others decisions over the course of many repetitions with communication. Thus, in some sense, this is our simplest design for considering pure measure-for-measure behavior.

High-Endowment Experiments with One-Shot Communication

In Experiment 1 (Table 4), the subjects stressed that they wanted to obtain a fair outcome where everyone received the same payoff. The subjects agreed upon a strategy of investing 6 tokens each in the CPR. While the agreement was not at the optimum, if all participants followed this agreement, they earned 89% of the optimum yield. The experiment lasted 22 rounds after the single communication round, leaving 21 rounds x 8 decisions to seek evidence of measure-for-measure reactions. Figure 2 shows how the reactions appear in reaction space. In 53% of all decisions (89/168) a subject invested at the agreement in round t in response to an average investment equal to the agreement in t-1. This can be interpreted to mean: the individual knows that on average the others kept to the agreement in t-1, and so the individual keeps to the agreement in t. This 53% is represented in Figure 2 in parentheses next to the word "AGREEMENT." Besides the 53% of all reactions at the agreement point, there were an additional 29% inside the measure-for-measure box. This is depicted in Figure 2 by the number 82% within the measure-for-measure box which includes the reactions at the agreement point, the Nash point, and interior to the box. There were no observations of one-shot Nash. This is represented by the 0% in parentheses next to NASH on the figure. Measure-for-measure responses are only defined between the AGREEMENT and one-shot NASH. In this experiment, and, as we shall see in most one-shot communication experiments, a noticeable percentage of players stick to the agreement when the group average is less than the amount agreed upon. In this experiment, for example, 7% of all responses were of the form where "i's reaction is 6 in round t, when the other's average in t-1 was less than 6." This is represented by the number 7% above the line extending leftward from the agreement point. There are two other types of reactions worth emphasizing. One is the optimum. In this experiment we observed no reactions where the individual invested at the optimum in response to an investment in the previous round that averaged at the optimum. We define a large reaction as any reaction greater than or equal to the one shot best response to the agreement. For instance, the one shot best response to the agreement at 6 tokens is 15 tokens by the player breaking the agreement. In this experiment, there is only 1 large reaction (rounded to 1%), displayed next to LARGE REACTIONS. In this experiment, the measure-for-measure reaction is very much in evidence.

In Experiment 2 (Table 4), the participants again had only one communication session. After a short discussion, they agreed to invest 5 tokens each. They saw on their screens that one player had invested 25 tokens in each of the first ten rounds. Only one player speculated about the payoffs that the "all 25" player had obtained and mused that this player "could be coming up with real money if everyone else is pulling back." Unfortunately for the others, this player could make twice the money the others made by persisting in his behavior and was perfectly willing to exploit the reaction.[14] He had actively promoted the decision to select 5 rather than 6 tokens as their agreement. As his parting shot at the end of the round, he told the others, "So we all need to stick to it." This player did not follow the same heuristic as the others. He adopted something closer to "never give a sucker an even break." With no further communication, the other seven players could see on their screens round after round that the same player invested 25 tokens. As shown in Figure 3, 31% of the responses were in the measure-for-measure box while 15% were large reactions--most of which were the actions of this one player.

In Experiment 3 (Table 4), the subjects disagreed on what the optimal investment was. They finally decided to invest 3 tokens each in round 11, 4 tokens each in round 12, 5 tokens each in round 13, and 6 tokens each in round 14 and then to pick the best (independently). During this trial phase, there were 2 large reactions, as well as 1 reaction out of sequence. Once the trial phase was completed, the modal subject choice from then on was 6 tokens. From this we infer that an implicit agreement at 6 had been reached. Since the group never had another chance to communicate, there is no way to check this inference. Clearly, the lack of a clear agreement point at the end of the communication period jeopardized the performance of any heuristic, such as measure-for-measure. As shown in Figure 4, 41% of the responses were in the measure-for-measure box, while 10% were large reactions.

Repeated Communication

In all four of the repeated communication, 10-token experiments, subjects followed their agreements with a high level of fidelity and responded to the few deviations in such a manner that one could safely argue that the subjects followed a measure-for-measure response in these experiments (reported in Table 2). The response diagrams for these four experiments all have higher than 97% of the responses in the measure-for-measure box, and almost all of these are at the agreement point. For this reason, we have not reproduced these response diagrams here.

As discussed earlier, the 25-token design is behaviorally a far more difficult situation than the 10-token design. We conducted 6 experiments with high endowments and repeated opportunities to communicate. In all 6 experiments, subjects reacted consistently with measure-for-measure, with at least 75% of all reactions in the box. We now consider each experiment in some detail.

In Experiment 1 (Table 3), subjects agreed to invest 6 tokens each. Thus, the agreement point in reaction strategy space is the point (6,6). The big difference between this experiment and the previous ones is that not a single reaction of the form (6,6) was ever observed. This group was literally never at the agreed-upon point. Nevertheless, the group did achieve a reasonable net yield (70%), and stayed in the vicinity of the agreement. In the 12 rounds where reactions could be observed following the initial communication round, 93% (89/96) of the reactions lay within the measure-for-measure box, as shown in Figure 5. There were only 7 reactions lying outside the box, and none of these were large. This is especially impressive given that there are no observations at (6,6).

The transcript of this experiment provides evidence about the expressed thoughts of the subjects as they coped with the continuing problem of defecting members. In the first rounds, seven subjects invested at the agreement and the eighth subject (Player C) invested two tokens over the agreement. After considerable discussion about what to do, they finally agreed that "staying with 6 is the best." The last two comments made before they returned to their terminals were:

Player B: Let's not get greedy. We've just got to start trusting.
Player H: Let's everyone do 6.

In the next Round, the 12th, Player C increased investments in the CPR from 8 tokens invested in Round 11, to 19 tokens. This constituted a real challenge to their agreement and an affront to the other players. Player A invested 7 rather than 6 tokens (consistent with measure-for-measure strategy). All the others stayed with the agreement and invested 6 tokens. After this round, the discussion opened with:

Player B: This should be our last meeting–if we can't get some trust, we might as well go back and screw each other over. We could all make more money if we could stick together, but if some are going to do the others in, then, we just should go. Does *everyone* agree to do the same thing?
Player D: If there is any objection to this, can we just plain hear why not?
Player H: Well, it is obvious that someone is making a little more money.
Player B: Well, they know that they are going to make more money, they could probably make all of two bucks, but still, I mean, if we go back to the way we were, none of us will make as much.
Player E: Let's try it one more time.
Player H: No, let's go back to the way we were doing it.
Player D: If you do, you sure lose!
Player G: If you don't work together, you lose.
Player E: That person will do it, whatever we agree to.
Player H: Does anyone want to confess?

Player D: Let's try one more time.
Player G: If this doesn't work, then forget all about it.
Player H: Want to try to invest 6? Let's try it.
Player B: Let's go for 6. [Player B then looks at each and every one of the other 7, points to each one, and looks at each one directly in the eye.] It shouldn't take very long for anyone to put in 6 in Market 2!.

After this dramatic close, Player C dropped back to the agreed-upon 6 tokens in Round 13, but Player A invested 8. In the discussion following Round 13, the players were so glad to be close to their agreement that they simply congratulated themselves on getting closer and asked to return to their terminals early. They had similarly short discussions from then on. After the 15th round, for example, they had the following exchange:

Player H: Not everyone is investing 6.
Player B: Evidently not.
Player C: Unless everyone keeps to it, it starts to get away from us.
Player H: Let's say we invest 6 again. Obviously somebody is cheating, but what can we do? But the rest of us can just continue to invest 6.

At a still later point, Player E suggested that they dump whatever they wanted into Market 2. Player H disagreed and pointed out that "we screw ourselves too." The transcript reflects a group of subjects' trying to grapple with a situation on the brink of disaster. Instead of going over the brink, their measured responses to the provocation sustained behavior close to their agreement, even though they never achieved perfect compliance.

In Experiment 2 (Table 3), the participants miscalculated the optimum at 50 tokens (instead of 36) and devised a rotation scheme whereby 6 individuals invested 6 tokens and 2 individuals invested 7 tokens. They had perfect compliance to their rotation system through Round 20, when one subject invested 11 rather than 6 tokens. Given past experience in experiments with 20 rounds, this may have been an "end effect." The discussion after Round 20, reproduced earlier in this paper, reflects individuals who are puzzled why someone would break their agreement. They resolved to return to their rotation scheme. They did return to their terminals and continued with perfect compliance from there on. They achieved 84% of the potential yield, rather than a higher percentage, because they had miscalculated the optimum and not because they had difficulty keeping to their agreement.

In Experiment 3 (Table 3), the players again overestimated the number of tokens that was optimal and agreed to invest 50 each round for four rounds (with a rotation system) and then 49 tokens each round. They faced only 3 defections during the course of their experiment. In the discussion following these defections, the players stressed the importance of not "messing it up" by small deviations and never discussed the possibility of punishing those who deviated. The central focus was on keeping the agreement going still further.

In Experiment 4 (Table 3), the subjects initially miscalculated the optimal investment level, but used their discussion to improve their agreement. By the last five rounds, they obtained 99% of the yield. Since they never faced a defection throughout the experiment, they never discussed a response for coping with this problem.

Experiment 5 (Table 3) was unique in one crucial respect. These subjects agreed to invest 1 token each in the CPR. This represents by far the worst agreement ever reached, with a potential group yield of only 40%. This agreement at the point (1,1) further creates the largest measure-for-measure box, with corners at (1,1) and (8,8). A large box is really easy to hit; indeed, 75% of all reactions in the 13 periods following the agreement landed in the box (see Figure 6). Despite this deficient agreement, subjects held to it for 7 rounds. Then the *same* player who had suggested the agreement in the first place made the largest possible reaction, 25 tokens.[15] A lively discussion ensued, as reported earlier in this paper. In the last 5 rounds of the experiment, there were 17 double-digit reactions, and the agreement clearly unraveled. The combination of deficient agreement and unraveling meant an overall average yield of only 37%, by far the lowest of the set of repeated communication, 25-token experiments.

Experiment 6 (Table 3) also helps illuminate how individuals who follow a measure-for-measure strategy avoid the complete dete)ration of an agreement when presented with small infractions by one or two individuals. In this experiment, the group agreed to invest 6 tokens each. While they did achieve some rounds of perfect compliance, they frequently faced rounds in which one or two persons invested 7 or 8 tokens rather than the agreed-upon 6. The participants discussed the possibility of trigger strategies at several points in their discussions and always rejected the idea. Here is one exchange:

Player D	What can we do to lose the most?
Player A	Lose the most?
Player D	Yeah, to get back at her--point at E (who was suspected of having overinvested).
Player A	But that hurts us all as well.
Player D	We probably don't have that many rounds left to really worry about this stuff of putting one more penny than we have agreed on. Let's just keep on putting in those 6's--and let them have the benefits of their stupid penny.

At a later juncture, one player commented that the set of reliable players is even smaller (while only two people had defected, one of those individuals had never defected before). This was followed with:

Player E	What are we going to do, are we going to go for a free-for-all?
Player B	Go for a free-for-all? Shucks no, we all lose.
Player D	No, we all lose.

The discussion rounds in this experiment were quite heated, but by stressing the fact that they would all lose if they moved too far away from the agreement point, the group was able to gain 84% of net yield even when facing the problem of repeated but small defections.

Summarizing, from the results of the 6 repeated communication, 25-token experiments, we find high rates of measure-for-measure reactions, at least 75% in all cases and at least 93% in five cases. We find very low rates of large reactions, never higher than 3%, with no large reactions whatsoever in four cases. In the five experiments where the initial agreement promised a high average yield (at least 90%), measure-for-measure reactions enabled groups to obtain on average 78% yield in a very challenging situation. Of course, measure-for-measure reactions cannot salvage a very deficient agreement.

Conclusions: Communication, Bounded Rationality, and Behavioral Heuristics

The above discussion of measure-for-measure reactions provides part of an explanation of "Why so much cooperation in a laboratory setting?," but only part. Communication allows individuals to agree on a joint strategy and to begin a process of building trust in others to abide by that agreement. When sanctioning is not available, trust has to be built through communication and consequent changes in patterns of behavior. When behavior is relatively close to the agreed-upon level, most individuals respond to deviations in a very measured fashion. When most individuals use a measure-for-measure response, even in challenging situations, they are able to gain joint returns close to the level agreed upon. Their closeness to optimality depends both on the yield potential of their agreement and on their rate of compliance. Individuals who exhibit measure-for-measure reactions are able to sustain cooperation for an extended period and reap the benefits of doing so.

On the other hand, when one or a few individuals do *not* respond consistently with measure-for-measure and are able to deviate in an extreme manner from an agreement (have available sufficient resources to be very disruptive to attempts by others to form near optimal agreements), measure-for-measure responses are not very effective. This is especially problematic when players communicate only once. The ability to chastise offenders verbally on a repeated basis is essential to preventing agreements from unravelling. In the 10 experiments where individuals reacted in a measure-for-measure fashion (greater than 85% in the box), either by sticking to their agreements or by keeping deviations small, yields averaged 87%. In the 5 experiments where this was not the case, yields averaged only 46%.

Even if measure-for-measure reactions work, this still leaves unanswered why some groups exhibit them and others do not. Where do such reactions come from? One answer to this question starts with Selten's dictum that complete rationality is the limiting case of bounded or incomplete rationality (see Selten 1975, 35). From this perspective, behavioral responses like measure-for-measure are heuristics used by individuals as problem-solving tools when complete analysis is difficult and short-term self-interest dictates unsatisfactory long-term outcomes. These occur when the cognitive tasks are beyond the immediate scope of the individual and the game equilibria lead to outcomes that are highly suboptimal.

Individuals learn to use a repertoire of heuristics depending upon their experience and their perception of the situation in which they find themselves.

In simple situations where short-term self-interest leads to a near optimal outcome, individuals may very well exhibit behavior that closely parallels that predicted by a model of complete rationality. In simple situations where short-term self-interest leads to a highly suboptimal outcome, individuals may learn from experience or be taught by mentors that use of a heuristic may lead to better outcomes, as long as others follow similar behavior. In complex situations individuals may adopt heuristics as a first approach to learning about the decision situation.[16]

In a situation without communication and with many individuals, it is extremely difficult to initiate a process by which individuals learn a measure-for-measure heuristic. Similarly, if groups only communicate once, and some individuals adopt less cooperative strategies than measure-for-measure reactions, it is harder to sustain cooperation over time than when groups are able to discuss their joint behavior and outcomes continuously. The larger the group and the more difficult it is to communicate, the more unlikely it is that individuals will overcome social dilemmas. The same individuals who use a measure-for-measure response when communication is possible, may not use it when communication is impossible. Given the difference in behavior and outcomes by the same players in the same game prior to and after communication, our evidence supports this claim.

But once individuals communicate (and, especially if they can communicate repeatedly), they can build up trust through their discussions and by achieving better outcomes through their behavior. If individuals come to these situations with a willingness to devise sharing rules and to follow a measure-for-measure response, then communication facilitates agreement selection and the measure-for-measure response facilitates agreement retention. The measure-for-measure heuristic prevents the full unraveling of an agreement when minor deviations first start to occur, but is not effective when major deviations occur. In the latter event, no response other than a sanction directed at a large response is likely to be effective.[17]

In situations as complex as these CPR experiments, the evidence suggests that individuals perceive the world differently from the rational players of noncooperative game theory. Individuals come to these situations armed with an array of previously-learned heuristics. With communication, these individuals have a chance to discover the approaches others are using to the game. Without communication, they do not know what to do in the situation they face and adopt strategies that vary tremendously.

The adoption of a measure-for-measure heuristic enables individuals to start on a productive path toward higher joint outcomes without outside enforcers. So long as the population of individuals sampled for laboratory experiments has a sufficient proportion of individuals who know and use a measure-for-measure heuristic, individuals can use this shared knowledge or social capital as a resource for gaining substantially better outcomes than they would otherwise have gained. Even when groups discover individuals within their midst playing entirely different strategies, the restraint shown by the remaining individuals keeps their joint returns higher than they were when pursuing completely independent strategies.

Table 1. Experimental Design Baseline: Parameters for a Given Decision Period

Experiment Type:	LOW ENDOWMENT	HIGH ENDOWMENT
Number of Subjects	8	8
Individual Token Endowment	10	25
Production Function: Mkt.2*	$23(\Sigma x_i)-.25(\Sigma x_i)^2$	$23(\Sigma x_i)-.25(\Sigma x_i)^2$
Market 2 Return/unit of output	\$.01	\$.01
Market 1 Return/unit of output	\$.05	\$.05
Earnings/Subject at Group Max.**	\$.91	\$.83
Earnings/Subject at Nash Equil.	\$.66	\$.70
Earnings/Subject at Zero Rent	\$.50	\$.63

* Σx_i = 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.

** In the high-endowment design, subjects were paid in cash one-half of their "computer" earnings. Amounts shown are potential cash payoffs.

Table 2. Repeated Communication after Round 10 -- 10-Token Design
Summary Results: Average Net Yield as a Percentage of Maximum -- Design xxx..cxcx...cx

	Round				
Exp. #	1-5	6-10	11-15	16-20	21-25
1	26	26	96	100	100
2	35	21	100	97	100
3	33	24	99	99	--
4	37	39	94	98	100
Means	33	27	97	98	100

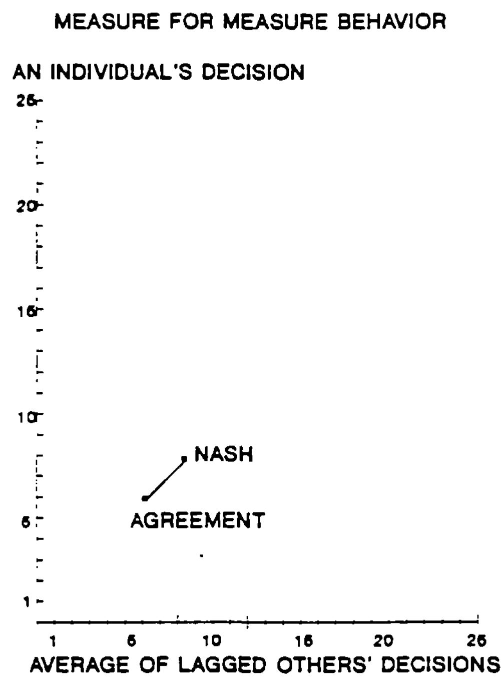
Table 3 Repeated Communication after Round 10 -- 25-Token Design
Summary Results: Average Net Yield as a Percentage of Maximum -- Design xxx..xcxcxcx

	Round				
Exp. #	1-5	6-10	11-15	16-20	21+
1	35	-43	76	75	54
2	60	8	85	82	85
3	4	-8	61	68	68
4	-60	13	80	93	99
5	-24	-3	40	67	-15
6	36	-41	84	86	80
Means	8	-13	71	79	62

Table 4. One-Shot Communication after Round 10 -- 25-Token Design
Summary Results: Average Net Yield as a Percentage of Maximum -- Design xx .cxx...x

			Round			
Exp. #	1-5	6-10	11-15	16-20	21-25	26+
1	-48	-20	89	89	85	83
2	-73	-16	45	-0	12	32
3	-2	-2	88	48	31	61
Mean	-41	-13	74	45	43	59

Figure 1. Linear and Extended Measure-for-Measure



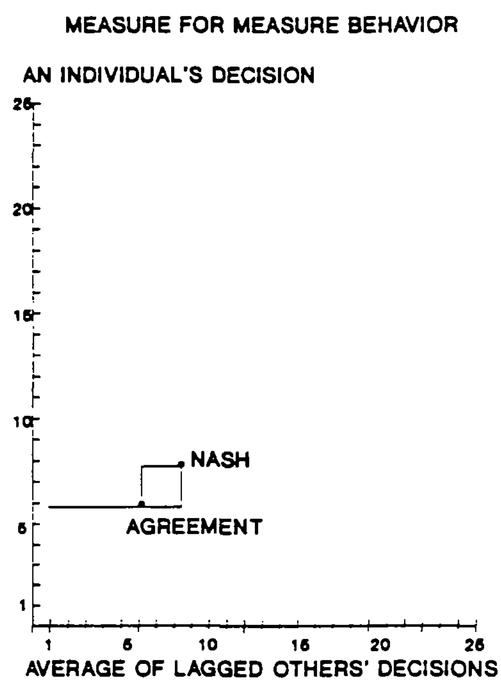


Figure 2. Measure-for-Measure
Experiment 1 - One Shot Communication

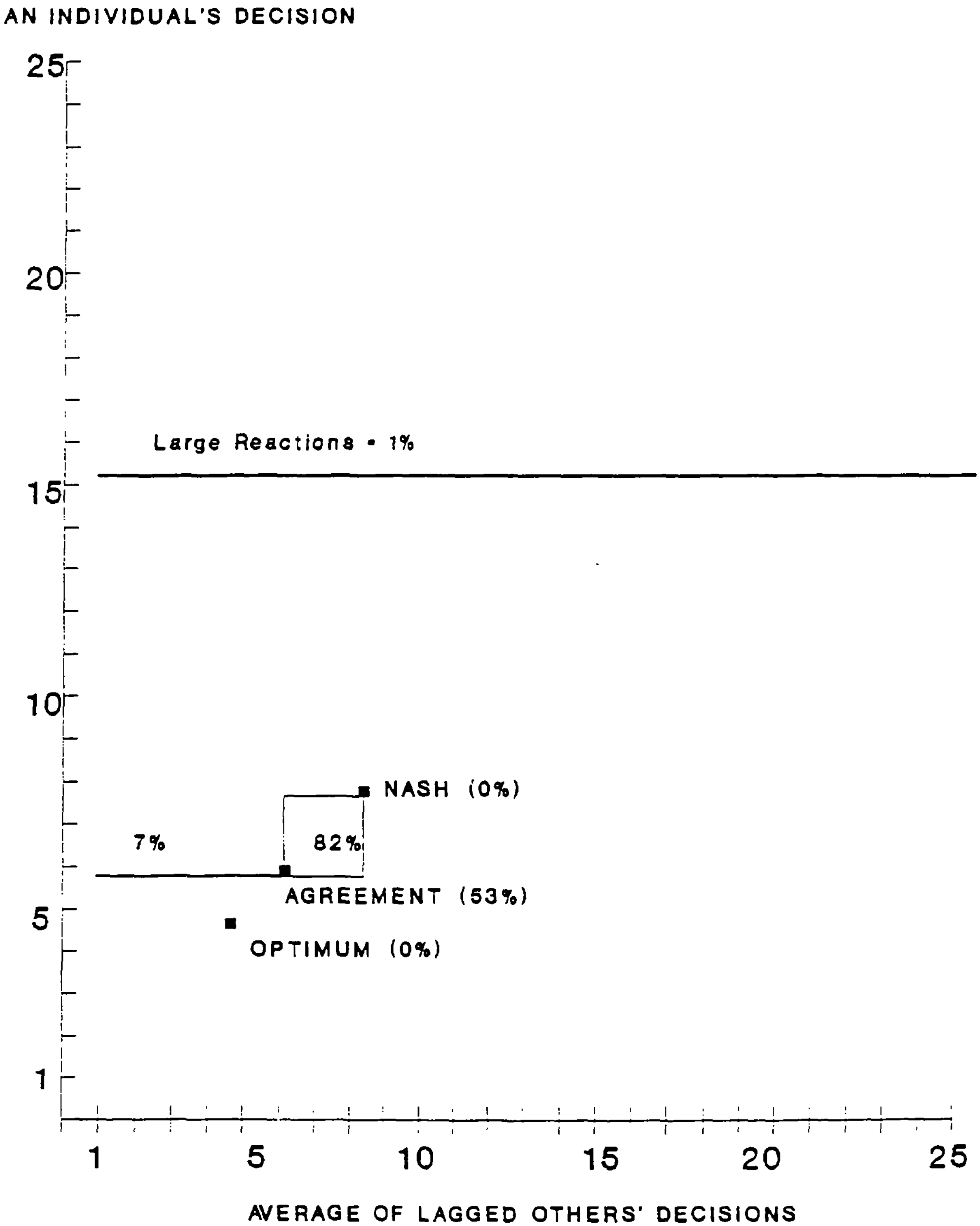


Figure 3. Measure-for-Measure

Experiment 2 - One Shot Communication

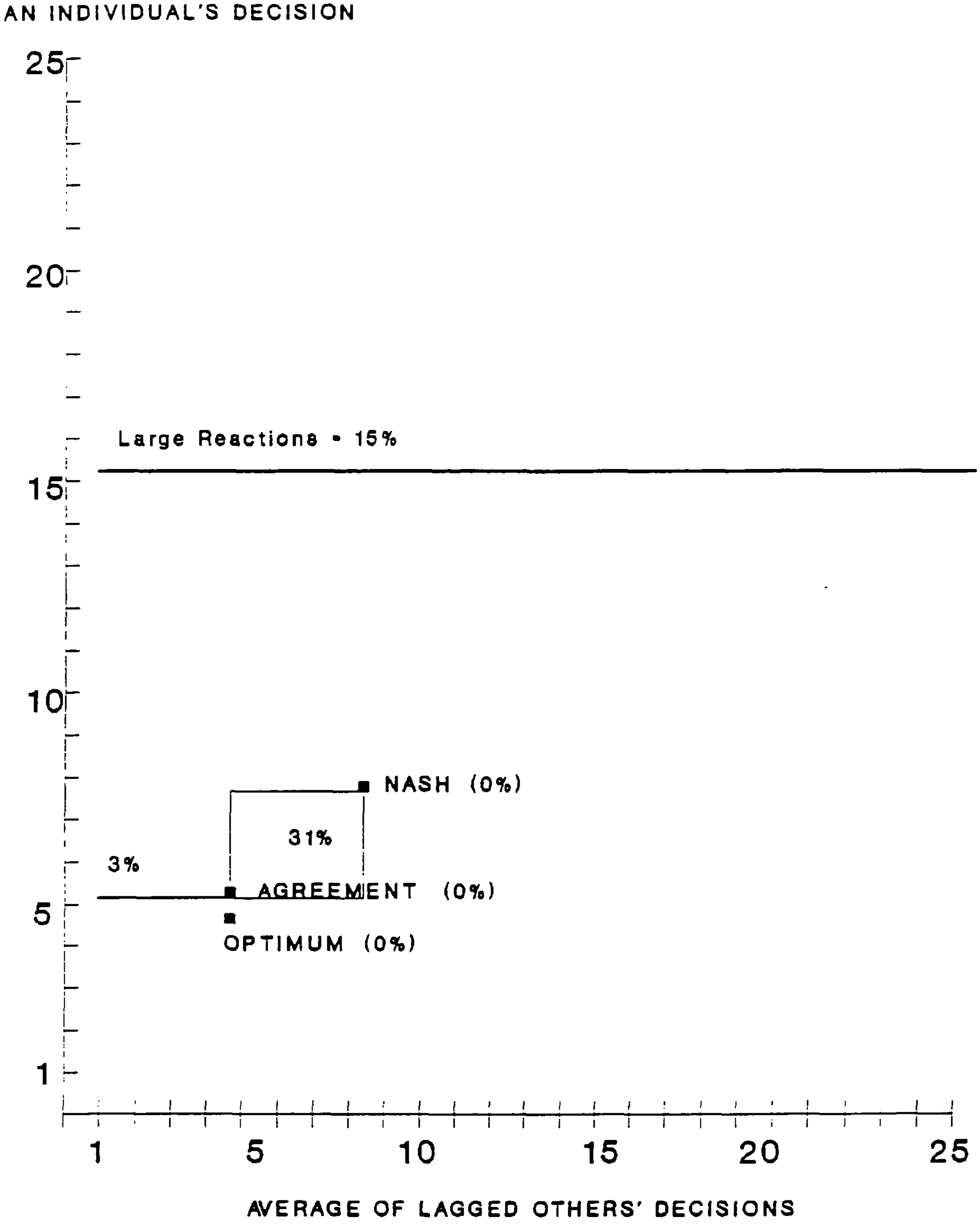


Figure 4 Measure-for-Measure
Experiment 3 - One Shot Communication

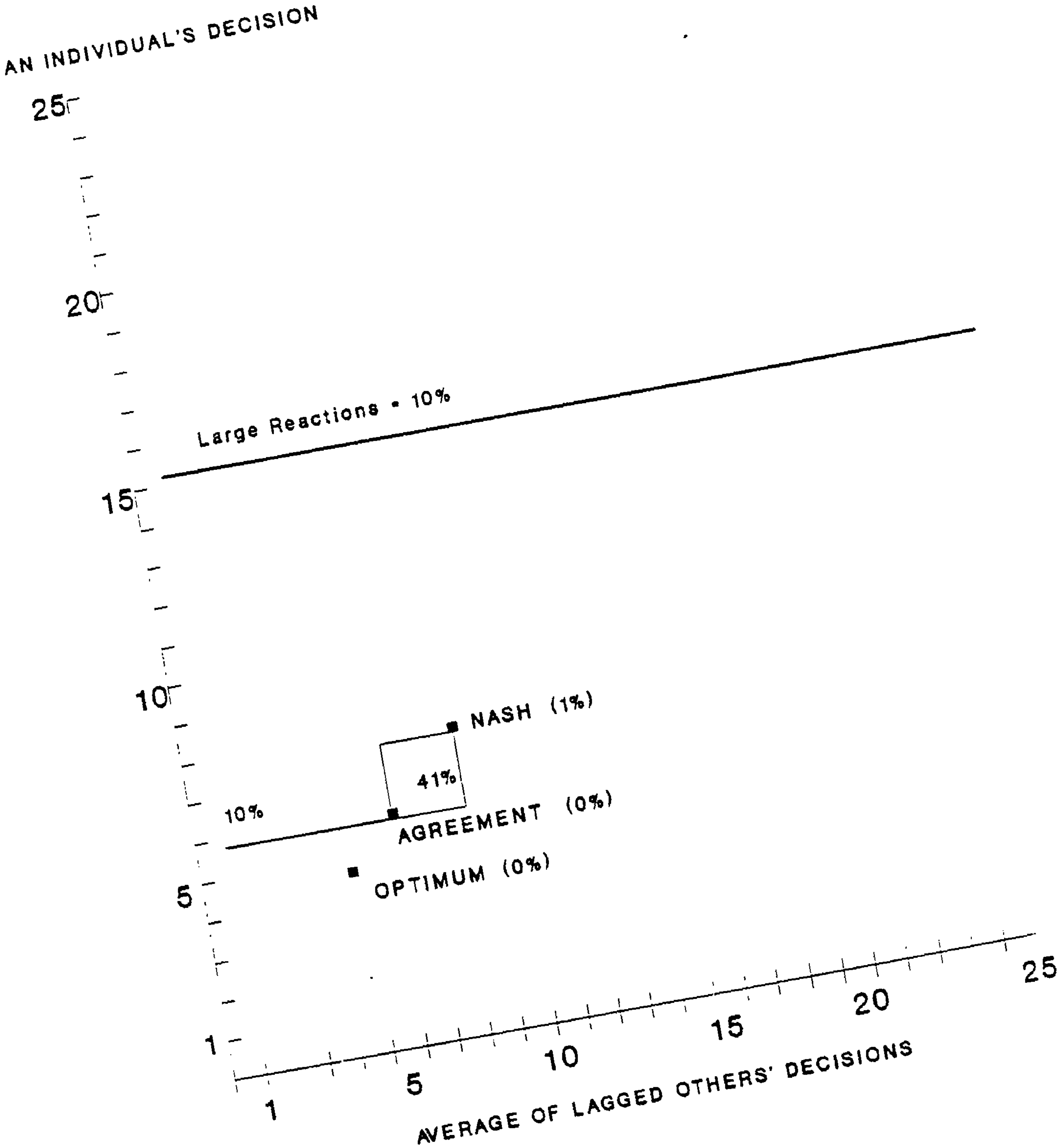


Figure 5. Measure-for-Measure
Experiment 1 - Repeated 25 Token

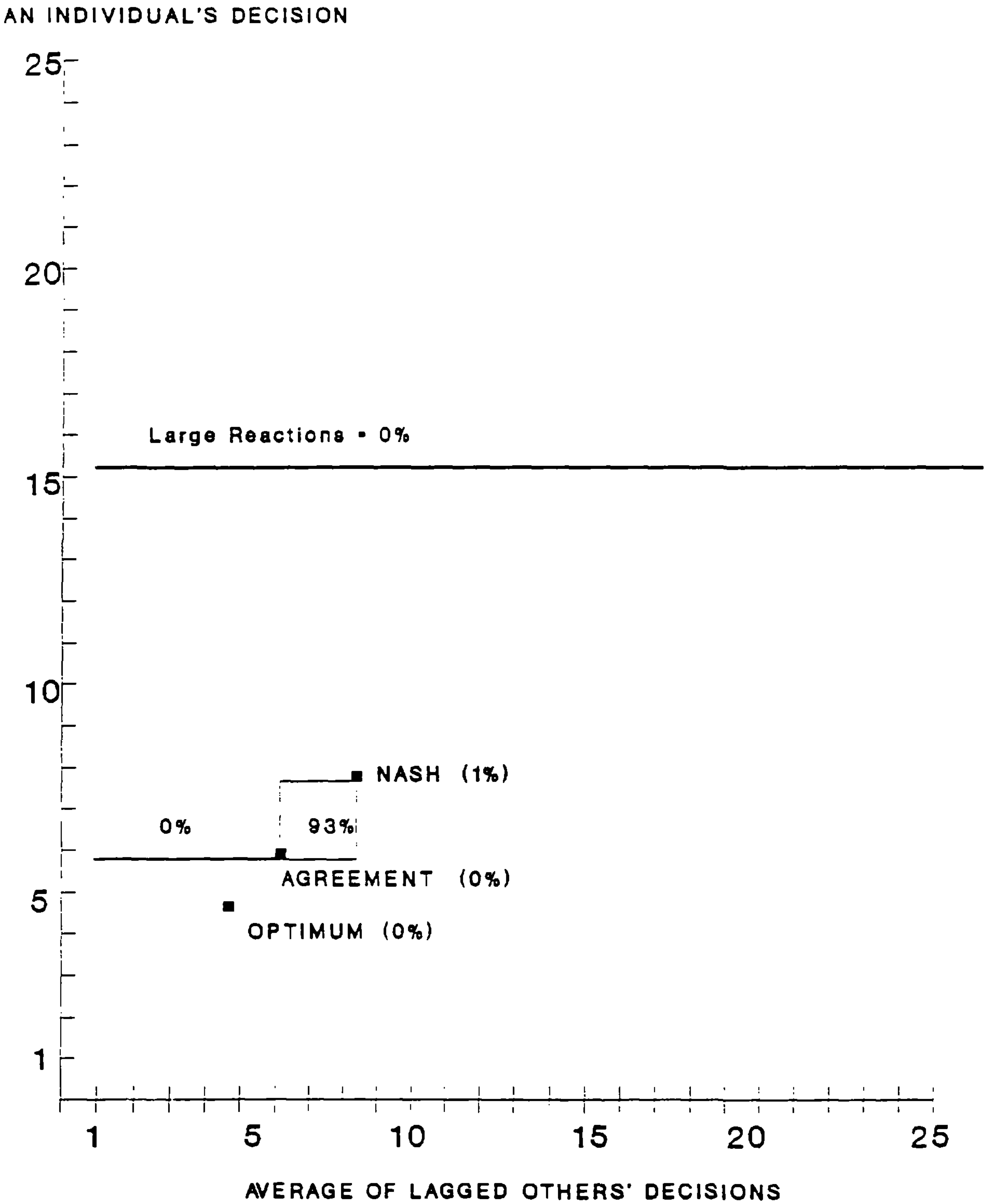
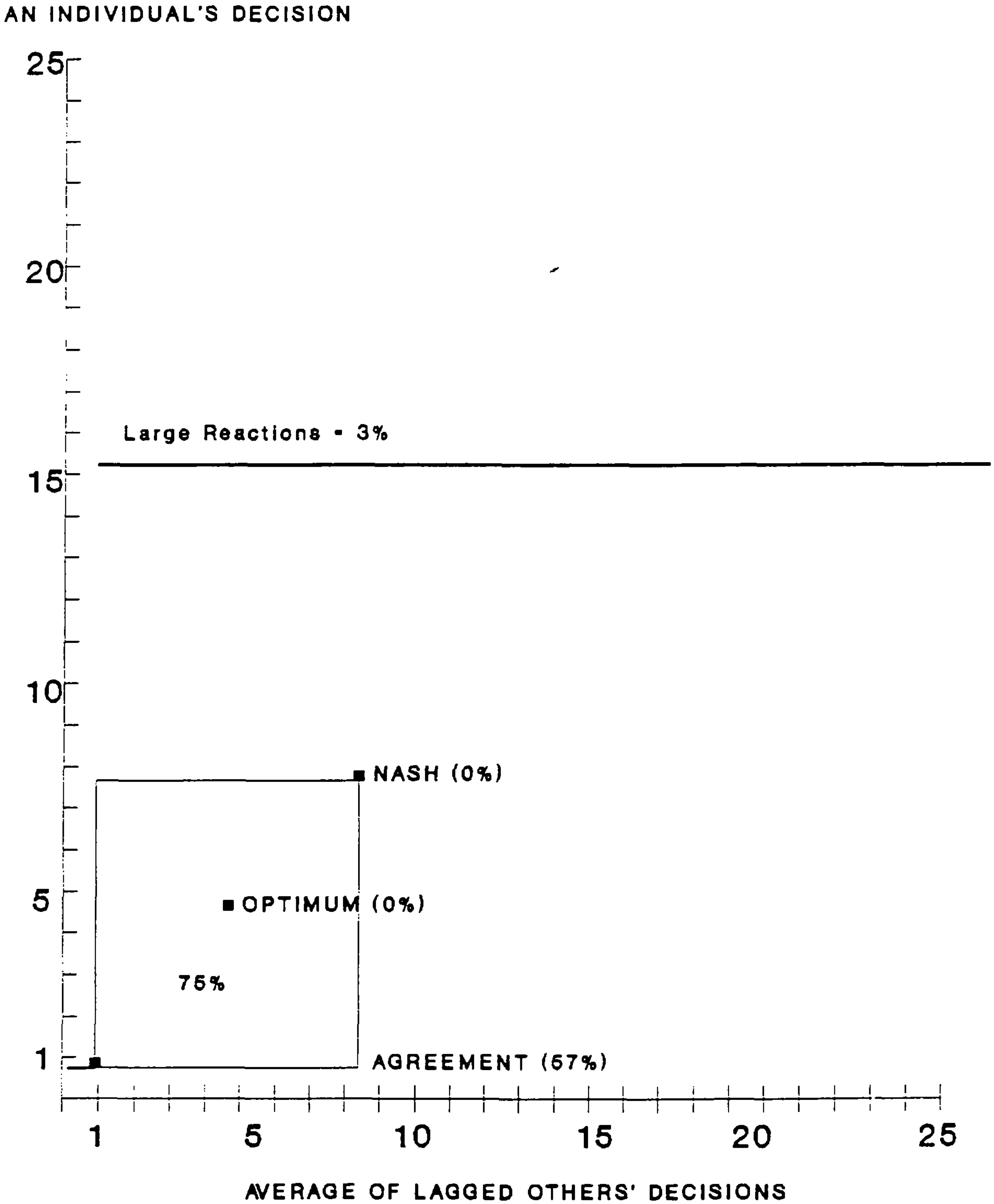


Figure 6. Measure-for-Measure
Experiment 5 - Repeated 25 Token



1. See Banks and Calvert (1992a, 1992b) for an important discussion of the theoretical significance of communication in incomplete information games.

2. See E. Ostrom and Walker (1991) for a more detailed discussion of the role of communication and the experimental evidence summarized here.

3. A complete set of instructions is available from the authors upon request.

4. Subjects were randomly recruited from initial runs to ensure that no group was brought back in tact. The number of rounds in the initial experiments varied from 10 to 20.

5. Investment in the CPR beyond the maximum net level is termed "rent dissipation" in the literature of resource economics. This is conceptually akin to, but not to be confused with, the term "rent seeking," which plays an important role in political economy and public choice. For the latter, see Tullock (1967) and Krueger (1974).

6. See Walker, Gardner, and E. Ostrom (1991) for details of this derivation.

7. An alternative measurement of performance would be to calculate overall experimental efficiency (actual earnings as a percentage of maximum possible earnings for the group). In this decision situation this measurement has the undesirable property that for any given level investments in the CPR, overall efficiency is different according to the number of tokens remaining to invest in Market 1. Further, our use of net yield gives a more accurate measure of the effect of behavior on the CPR, our primary interest.

8. Each person was identified with a badge that was unrelated to their player number. This facilitated player identification in our transcripts. If unanimous, players could forego discussion.

9. These low-endowment communication experiments were conducted very early in our research and used a modified 10 token payoff function for market 2 ($15(\Sigma x_i)-.15(\Sigma x_i)^2$). Yield as a percentage of maximum from experiments without communication using this payoff function closely parallel the yields observed in our 10 token low-endowment baseline design. Across 20 decision periods, the difference in mean yields between experiments using these two alternative payoff functions for market 2 was only 6.4%, slightly higher in the low-endowment baseline design presented in the text.

10. Subjects are told that the experiment will last about one and a half hour and have already experienced training experiments that lasted no more than 20 rounds. In a similar set of public good experiments, where the end period was specifically announced, similar behavioral outcomes were observed (see Isaac and Walker 1988a, 1988b). For finitely repeated games with a unique equilibrium, one can still invoke grim trigger strategies, but they will necessarily involve incredible threats and promises, whose incredibility will come due in a finite amount of time.

11. For important work on incomplete information see Banks and Calvert (1992a, 1992b).

12. See El-Gamal, McKelvey, and Palfrey (1991) for an intriguing effort along this line. The authors note that computation of "the sequential Nash predictions for the one set of parameters we used took approximately 40 CPU hours on a Cray XMP/18 supercomputer. The computing time goes up exponentially in the number of moves per game and number of games each subject plays" (1991, 15).

13. Colleagues working with Reinhard Selten in the Department of Economics at the University of Bonn have developed and tested a series of behavioral strategies related to various types of games. See Rockenbach and Uhlich (1989) on two-person characteristic function games; Mitzkewitz and Nagel (1991) on ultimatum games with incomplete information.

14. When the other players contributed 5 tokens each, someone contributing 25 tokens could make 8 "experimental cents" on each token in the CPR and only 5 "cents" on the same tokens in the alternative investment. That meant that the individual investing 25 tokens made a total of 200 "cents" on any round when the others invested no more than 35 tokens in total. The others made 140 "cents." If everyone had followed the agreement, all would have made 185 "cents." Subjects were paid one half of the "experimental cents" they earned in the 25-token experiment.

15. The heuristic this player may have been playing could be described as: "Set the suckers up for a preemptive strike."

16. See Groner, Groner, and Bischof (1983) for a general discussion of heuristics.

17. In other experiments we have found that players are willing to impose costly sanctions one on another in order to control large responses of this type (Ostrom, et al. 1992).

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