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# RENT DISSIPATION AND PROBABILISTIC DESTRUCTION OF COMMON POOL RESOURCES: EXPERIMENTAL EVIDENCE

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## ABSTRACT

Using experimental methods to test a game theoretic model of destruction in a common pool resource environment, this paper investigates whether the possibility of destruction will significantly alter choice behavior in the resulting game. When there is a nonnegligible probability of destruction at the subgame perfect equilibrium, the common pool resource is in every case destroyed and, in most cases, rather quickly. Even when there is a second subgame perfect equilibrium which is completely safe and yields near optimal rents, subjects do not stabilize at this equilibrium. The consequence of this destruction is in every case a significant loss in rents.

## I. INTRODUCTION

Common pool resources (CPRs) are natural or man-made resources from which it is costly (but not necessarily impossible) to exclude potential beneficiaries. The work of scholars such as Gordon (1954) and Hardin (1968), argues that when individuals use such resources jointly, each individual is driven by an inexorable logic to withdraw more of the resource units (or invest less in maintenance of the resource) than is optimal from a group perspective. That is, rents which could be accrued from the resource are dissipated relative to their optimal level.

The problems that appropriators face can be usefully clustered into two broad types: **appropriation** and **provision**. In appropriation problems, the production relationship between yield and level of inputs is assumed to be given and the problem to be solved is how to allocate that yield (or input activities to achieve that yield) in an economic and equitable fashion. Provision problems, on the other hand, are related to creating a resource, maintaining or improving its production capabilities, or avoiding its destruction.1

Our experimental research has concentrated on the investigation of stationary (non-time dependent) appropriation problems in limited access CPR environments.2 This paper extends our earlier work by introducing a significant nonstationarity, the possibility of resource destruction, into the decision framework. Our previous results demonstrated the significance of the rent

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1. See Gardner, Ostrom, and Walker (1990) for further discussion of the conceptual framework of a CPR dilemma.

2. See Walker, Gardner, and Ostrom (1990) for details of the prior experimental work related to a stationary CPR decision environment.

dissipation problem in the context of a repeated choice noncooperative decision environment. Here we investigate the behavioral question of whether the possibility of destruction will significantly alter appropriation behavior in the resulting game. Our primary results are that: (1) if there is a unique symmetric subgame perfect equilibrium involving a high one-period probability of destruction, the resource is destroyed in six periods or less; (2) if there are at least two symmetric subgame perfect equilibria (one of which is clearly better in payoff space) then group behavior in some instances tends to focus on the better equilibrium, but in general this equilibrium cannot be sustained and the resource is destroyed.

Our investigation focuses on a resource which, if there is no human intervention, has 0 probability of destruction. On the other hand, if there is appropriation activity, there is a positive probability that the resource is destroyed. This probability grows with appropriation levels, until it becomes 1 at some upper bound. Clearly such a CPR is time dependent: if it is ever destroyed, its flow of value from that date on is 0. Alternatively, if appropriation levels are zero, the CPR's flow of value is zero. Appropriators then face a tradeoff between jeopardizing the life of the resource and gaining any rents from it. It is the behavior in response to this tradeoff which we examine in our experimental environments.

The paper proceeds as follows: Section II describes the decision task faced by our experimental subjects and summarizes results from our stationary "baseline" appropriation environment. In section III we discuss the design and results from our first nonstationary (Design I) environment. Section IV summarizes results from a second nonstationary (Design II) environment. Conclusions are reported in section V.

## II. THE APPROPRIATION and RENT DISSIPATION PROBLEMS

### The Experimental Environment

The theory of rent dissipation follows from a behavioral assumption that appropriators will ignore the impact of marginal increases in appropriation on the return other appropriators' receive from their appropriation activities. In open access environments it follows that such behavior will yield an outcome in which appropriation continues as long as the average return from appropriating exceeds the marginal costs of such appropriation (full rent dissipation). In a limited access environment, the Nash equilibrium prediction is limited rent dissipation. Our baseline experiments examine the severity of this problem in a repeated noncooperative decision making environment with limited access.

The full design and results of our baseline experiments are detailed in Walker, Ostrom, and Gardner (1989 and 1990). The experiments were conducted using subjects drawn from the undergraduate population at Indiana University. Students were volunteers recruited primarily from principles of economics classes. All experiments were conducted using the PLATO(NOVANET) computer system at Indiana University. This interactive system allows for minimal experimental interaction, across experiment control on procedures, and facilitates the complex accounting that follows each decision period. At the beginning of each experimental session, subjects were told they would be making a series of "investment" decisions, that all individual investment decisions were anonymous to the group, and that at the end of the experiment they would be paid privately (in cash) their individual earnings. Subjects then proceeded, at their own pace, through a set of instructions that described the investment decisions. Below, we summarize the decision task.

*Subjects were informed that in each period they would be endowed with a given number of tokens, which they would invest 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.*

Thus, our environment most closely parallels that of a limited access CPR (see, for example, Clark, 1980; Cornes and Sandler, 1986; and Negri, 1989).

All experiments were conducted using experienced subjects, where experience implies that each of the subjects had participated in a similar decision making experiment. The use of experienced subjects increases the likelihood that subjects understand the decision problem and the ramifications of alternative levels of individual and group investment decisions. Experienced subjects were recruited randomly to insure that no prior experimental group was brought back intact.

The parameters for our experimental environment are shown in Table 1. Conditions were constant within a given experiment. All experiments were conducted for 20 decision periods.3 Players were endowed with 25 tokens per period. Each token invested in Market 1 yielded a certain return of $.05. Given a strategy space for each player of $x_i \in \{0,1,2,....,25\}$, where $x_i$ denotes the number of tokens in Market 2, the within-period payoff for player i $u_i(x)$, in cents, is:

3. Subjects were notified that their cash payoffs would be one half of their"PLATO" dollars earned during the experiment.

$$u_i(x) = \begin{cases} 125 & \text{if } x_i = 0 \\ 5(25-x_i) + (x_i/\Sigma x_i)(23\ \Sigma x_i - .25(\Sigma x_i)^2) & \text{if } x_i > 0 \end{cases} \qquad (1)$$

where $x = (x_1, \ldots, x_8)$ is the vector of strategies of all players.

**Theoretical Predictions for the Baseline Design**

This parameterization for our baseline (stationary) games allows for three theoretical predictions. Figure 1 illustrates group behavior that would be consistent with these alternative predictions. This symmetric game has a unique Nash equilibrium with each subject investing 8 tokens in Market 2 (denoted T1).[4] At the Nash equilibrium, subjects earn approximately 40 percent of maximum rents. A group investment of 36 tokens yields a level of investment at which MRP = MC and thus maximum rents (denoted T2). Conversely, a group investment of 72 tokens yields a level of investment at which ARP = MC and thus zero rents from Market 2 (denoted T3).

**Summary Results: Baseline Experiments**

The baseline results are summarized in Table 2 and Figure 2. Aggregating across all experimental periods, the average level of rents equalled -3.16 percent. The average tendencies for all three experiments are highlighted in the top panel of Figure 2. In the bottom panel of Figure 2 we display the across period rent results for each experiment. Several characteristics of the individual experiments are important. Similar to results reported in earlier stages of our research, we observed a pulsing pattern of investments across periods, where rent is significantly reduced, at which time investors tend to reduce investments in Market 2 and rents increase. This pattern tends to repeat itself throughout the experiment. We are not implying that we found symmetry

4. See Walker, Gardner, and Ostrom (1989) for details of this derivation.

across experiments in the magnitude of "rent peaks" or the timing of peaks. The general cyclical pattern is consistent, however, throughout our experiments. In no experiment did we find a pattern in which rents converged to the maximum. Note that low points in the pulsing pattern were at rent levels far below zero. There was, however, some tendency for the variance in rents and the level of rent dissipation to decrease over repeated decision trials. In fact, if we focus on the last 10 periods of each experiment, we observe less variation in rent cycles and a mean level of rent accrual of 21.2 percent. We did not observe, however, any clear signs that individual investments in Market 2 were stabilizing at the Nash equilibrium.5

## III. EXPERIMENTS WITH DESTRUCTION - DESIGN I

Our Design I and II experiments utilize the same payoff parameters as in our baseline experiments. The only change in strategy space relates to the way in which investment decisions affect the probability of ending the experiments (destruction). The subjects in both of our Design I and II experiments had previously participated in an experiment using the parameters described for our baseline experiments.6 Thus, they were experienced in the decision environment for a non-time dependent experiment. Prior to making investment decisions in our Design I destruction experiments, the subjects read an announcement which can be

5. We have conducted other experiments with a similar design in which we allowed the experiments to run for 30 periods. We still do not observe individual behavior stabilizing at the Nash prediction. However, at the aggregate level, it is the Nash prediction which best describes our results. We have also conducted experiments in which we increased the payoff loss due to rent dissipation. The general tendencies for rent dissipation are not affected by such parametric changes.

6. No subject group was brought back intact for the Design I and II experiments.

summarized as follows.7

*The subjects were notified that the experiment would continue up to 20 rounds. After each decision round a random drawing would occur which would determine if the experiment continued. For every token invested in Market 2 by any participant, the probability of ending the experiment increased by one-half percent. For example: if the group invested 50 tokens total in Market 2, the probability of ending the experiment was 25%. The drawing at the end of each round worked as follows: a single card was drawn randomly from a deck of 100 cards numbered from 1 to 100. If the number on the card was equal to or below the probability of ending the experiment for that round (as determined by the group investment in that round) the experiment ended. Otherwise the experiment continued to the next round. (See Appendix A for the actual announcement).*

Note that this kind of destruction environment is more severe than one which might be experienced in the naturally occurring world. If the CPR is destroyed here, the experiment ends. In the naturally occurring world, if the CPR were destroyed we would generally expect alternative investment opportunities to be available. Thus, our design favors a behavioral result in which the potential for destruction significantly reduces appropriation from the CPR.

Theoretical Predictions

The change from a stationary to a nonstationary environment has several

7. The experimenter reviewed the announcement with the subjects and answered questions. Note that in the destruction experiments subjects were told explicitly that the experiments would last up to 20 periods. In the baseline experiments, no such announcement was made. This information in the destruction experiments makes the optimization task tractable.

theoretical implications. We focus on two benchmarks: (1) the solution for the decision strategy which maximizes expected rents and (2) a Nash equilibrium prediction. We turn first to the maximization problem. Since achieving a maximum requires coordination among players, assume the existence of a rational agent who invests the entire group's tokens each period. Denote by $X_t$ the amount of the group's tokens invested in the resource, when there are t periods remaining: $0 \le X_t \le 200$ in our design. We solve the optimization problem using a dynamic programming argument assuming risk neutrality. This requires determining the optimal value function, $f_t(X_t)$ for each time remaining t, t = 1, 2,. . ., 20 in our design.

We begin the solution with one period remaining. Here $f_1(X_1)$ is given by:

$$f_1(X_1) = \max_{X_1} 5(200-X_1) + 23X_1 - .25X_1^2 \qquad (2)$$

where the first term on the right represents the payoff from the risk-free alternative and the remaining terms represent the return from the destructible resource. A routine calculation shows that the maximum is achieved at $X_1 = 36$ (this is just the monopoly solution from the stationary case). Substituting in (2), one has: $f_1(X_1) = 1972$. Now suppose that the decision maker has two periods to go; we seek $f_2(X_2)$. Here, the destructibility aspect emerges for the first time. The probability that the resource survives with two periods to go, $p_t = p_2$, is given by:

$$p_2 = (200-X_2)/200. \qquad (3)$$

If $X_2 = 0$, and no tokens are invested in the resource, it will not be destroyed; for $X_2 > 0$, there is an increasing probability of destruction. Now the two-period optimal return function is :

$$f_2(X_2) = \max_{X_2} 1000 + 18X_2 - .25X_2^2 + p_2(f_1(X_1)). \tag{4}$$

where $f_1(X^1)$ is 1972.

The reasoning behind (4) is that if the resource is destroyed, then there is 0 payoff in the last period; otherwise, the resource is exploited optimally with one period to go, resulting in payoff 1972. The optimal solution to (4) is $X_2 = 16$ and $f_2(X_2) = 3038.2$. Notice that we observe a drastic reduction in investment in the risky resource, from 36 to 16. Even though the decision maker is risk neutral, the value to be gained from not destroying the resource weighs in heavily against exploiting it in the current period. As we shall now see, this consideration becomes even stronger with three or more periods to go.

For the three-periods-to-go-problem, one solves:

$$f_3(X_3) = \max_{X_3} 1000 + 18X_3 - .25X_3^2 + p_3(3038.2). \tag{5}$$

to find that $X_3 = 6$ and $f_3(6) = 4046.1$.

We are down to only 6 units in the risky investment. We now show that with 4 or more periods to go, $X_t=0$. Not only don't you kill the goose that lays the golden egg, you don't even trim its feathers.

To see that $X_4 = 0$, consider the situation with 4 periods to go. One has:

$$f_4(X_4) = \max_{X_4} 1000 + 18X_4 - .25X_4^2 + 4046.1 - 20.23X_4 \tag{6}$$

where we have explicitly substituted (3) into the expression to make the point clearer. Since $f_4(X_4)$ is now everywhere decreasing in $X_4$, the optimal solution is $X_4 = 0$. Indeed, this will be the case for any $X_t$, $t \geq 4$.

We can now calculate the optimal rent to be extracted from the destructible resource, in expected value terms. During the first 17 periods, the resource is not exploited at all, yielding an aggregate return of 1000(17) = 17000. During the last three periods, investment levels are 6, 16 and 36 respectively, with an expected return of 4046.1. The overall expected return is therefore 21046.1, or just over $210.

A Nash equilibrium prediction for this environment can be determined using similar reasoning.8 Let $x_{it}$ denote the investment decision of player i at time t, when there are t periods remaining: $0 \leq x_{it} \leq 25$. Let $x_t = (x_{1t}, \ldots, x_{8t})$ be the vector of individual investments of time t; $u_{it}(x_t)$, player i's one-period return at time t when the group strategy $x_t$ is played; and $f_{it}(x_t)$, the value to player i from being in the game with t periods to play. The optimal return function for player i at time t, $f_{it}(x_t)$, is defined recursively as:

$$f_{it}(x_t) = \max_{0 \leq x_{it} \leq 25} u_{it}(x_t) + p_t(f_{i,t-1}(x_{t-1})), \qquad (7)$$

where $p_t$ is the probability that the resource survives and $u_{it}(x_t)$ is the one-period return function as in (1). In the event that the resource is destroyed, no further value is obtained. The probability ($p_t$) is given by equation (3), as before.

We begin the dynamic programming argument at t = 1. Since this is the last period, the equilibrium condition is that an equilibrium $x_{it}^*$ satisfy:

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8. The equilibrium we describe is symmetric and subgame perfect. It shares the backward induction logic of the optimum. There are other Nash equilibria, however, which are less compelling, due to their imperfection. There are also asymmetric equilibria which cluster around this symmetric equilibrium.

$$\frac{\delta u_{i1}(x_1^*)}{\delta x_{i1}} = 0, \text{ for all } i \qquad (8)$$

For these designs, equation (8) implies $x_{i1}^* = 8$, for all i. Substituting into (7), one has $f_{i1}(x_1) = 141$ cents.9 For the decision step at time t, one differentiates the right hand side of (7) to obtain:

$$0 = \frac{\delta u_{it}(x_t^*)}{\delta x_{it}} + f_{i,t-1}\ (x_{t-1})(-1/200) \qquad (9)$$

the last term arising from the effect of the probability of destruction on future earnings. In Table 3, we present the solution to (9) for the entire life of the resource, given that it lasts at most twenty periods, as well as the optimal solution. Three features of this symmetric subgame perfect path should be noted. In contrast to the optimal path, where only in the last 3 periods is there a positive probability of destruction, here there is a positive and growing probability of destruction throughout the experiment. At the outset, the 1-period destruction probability is approximately 27 percent, and it rises to 32 percent by the end. With 1-period destruction probabilities this high, it is unlikely (probability less than .05) that the resource would last 10 periods along this equilibrium path. This increased probability of destruction accounts for the lower overall value of the resource to investors, slightly less than $6 each, or $46 aggregate (8x(575) cents), as opposed to over $200 at the optimum. Finally, individual value stabilizes at 575 for infinitely long experiments. Thus, 20 periods is long enough to approximate steady state equilibrium behavior.

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9. For ease of presentation, we will assume in this derivation that tokens are divisible. Working out the recursive equations for the case of indivisible tokens leads to quantitatively the same result, to the accuracy of 1 token invested, or 1 cent in payoff.

## Experimental Results

The results of five experiments are summarized in Table 4. All five experiments yielded investment results well below optimum. The longest experiment lasted 6 periods. In this experiment, subjects earned only 35% of the rents which would be obtainable following the optimal path (see column 4). These results are striking. In a decision environment with a well-defined probability and significant opportunity costs of destruction, individual and group investments in Market 2 were well beyond optimum levels, while being evenly dispersed around the Nash path. See Appendix B for period-by-period aggregate investment.

We get a better picture of the behavior in this environment by looking at the decisions of individuals in the first decision period, summarized in Figure 3. First, only 2 of 40 individuals are playing the safe strategy of investing 0 tokens in Market 2. Further, the frequency of players investing 10 or more tokens in Market 2 is high (12 of 40). In each of the 5 experiments, at least 2 players followed a strategy of investing 10 or more tokens.

One might conjecture that, after an initial decision round with a significant probability of destruction, players would fall back to a safe strategy. In no experiment did all players fall back to cooperative strategies with low levels of investments in Market 2. Experiment 1 resulted in the most significant drop, with investments falling from an aggregate of 80 in period 1 to 32 in period 2. Even in this experiment, investments began to increase after period 2.

In summary, investments in Market 2 (the CPR) are reduced relative to an environment with no destruction. This reduction falls far short, however, of yielding an optimal path of appropriation from the CPR.

## IV. EXPERIMENTS WITH DESTRUCTION - DESIGN II

Our Design I is unforgiving in the sense that any investment in the CPR leads to some probability of destruction. Our second design adds a "safe zone" for Market 2 investment in order to investigate whether subjects might focus on a clear cut safe investment opportunity. The announcement to subjects for Design II can be summarized as follows.

> *The subjects were notified that the experiment would continue up to 20 rounds. After each decision round a random drawing would occur which would determine if the experiment continued. If the group invested 40 tokens or less in Market 2, the experiment automatically proceeded to the next round. If the group invested more than 40 tokens in Market 2, the probability of ending the experiment increased by one-half percent for each token invested in Market 2 by any participant. For example: if the group invested 50 tokens total in Market 2, the probability of ending the experiment was 25%. The drawing at the end of each round worked as follows: a single card was drawn randomly from a deck of 100 cards numbered from 1 to 100. If the number on the card was equal to or below the probability of ending the experiment for that round (as determined by the group investment in that round) the experiment ended. Otherwise the experiment continued to the next round. (See Appendix A for the actual announcement).*

### Theoretical Predictions

The solution for maximum rents in this design is quite simple. Since the allocation of 36 tokens to Market 2 leads to maximum rents and 36 tokens is in the safe zone, a single player would play 36 tokens each period to maximize rents. Subgame perfect Nash equilibria can be found using the same dynamic programming procedure as above. In Design II, the destruction probability is the same as Design I when $\Sigma x_{it} \geq 41$, but otherwise zero.10

We begin the backward induction with t = 1. Since this is the last period,

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10. In the first three experimental runs this upper bound was set equal to 40. This slight change had no apparent effect on behavior. We have therefore pooled all runs in the results reported here.

the equilibrium condition is that $x_{it}*$ satisfy equation (8) as before: $x_{i1}* = 8$, for all i. Substituting into (7), one has $f_{i1}(x_1) = 141$ cents. For the induction step at time t, one differentiates the right hand side of (7) to obtain equation (9), once again. Thus, it is clear that the equilibrium path computed for Design I remains an equilibrium for Design II, since this path never enters the safe zone.

However, there is another equilibrium path in Design II which is better in payoff space. This equilibrium path starts with $X_1* = 64$ with one period to go, but later switches to the boundary of the safe zone ($X_t* = 40$), for some critical time remaining t. We now show that the critical time is t=3. Consider $f_{i2}(x_2)$. Suppose all players except player i are investing a total of 35 tokens. If i invests 5 tokens, then he gets a sure payoff of $u_{i2}(5) + 141$, leading to an overall 2-period expected value of 306 cents. There is no threat of destruction in this case. Now suppose instead that player i makes the best response <u>in the destruction zone</u> to 35 tokens invested by the others. This turns out to be 17 tokens, leading to a 26% chance of destruction and an expected 2-period payoff of 314 cents. Thus, with 2 periods to go, staying in the safe zone is not an equilibrium. This situation is quite different for t = 3. Repeating the above calculations, the safe investment yields an expected payoff of 408 cents over the last three periods, while the investment of 17 tokens (still the best response in the destruction zone) yields a payoff of only 390 cents. Thus, with 3 periods remaining, the future value of preserving the resource is sufficient to justify staying in the safe zone as a noncooperative equilibrium. Finally, since expected future value grows with time remaining, once this backward induction path enters the safe zone, it stays there.11 Indeed, this equilibrium path pays nearly as well as the optimum path for Design II (invest 36 tokens each period and never risk destruction). Optimal value over 20 periods is approximately $265, while under the good equilibrium path, aggregate value is approximately $257.

Thus, there is a dramatic difference in payoffs between the good equilibrium and the bad one; and if the good equilibrium is played, the probability of destruction is nil until the endgame effect appears. Note that this environment gives a clear "focal" point for behavior. By investing 40 tokens the group receives very close to optimal rents (97 percent) and runs no risk of ending the experiment.

Experimental Results - Design II

The results of seven experiments are summarized in Table 5. In five of the seven experiments destruction occurred at early periods and consequently led to rent accrual far from the level consistent with the "safe" investment strategy. Of these five experiments, the longest experiment lasted 6 periods. All rents earned were under 30 percent of rents obtainable using the "safe" strategy (see column 4 of Table 5). In two of the seven experiments, destruction did not occur until late in the experiments (rounds 15 and 17). In these experiments, subjects earned 74 and 84 percent of the rents obtainable with the "safe strategy. At an aggregate level, it would appear that in these two experiments the possibility of destruction led to subjects focusing on the safe equilibrium strategy. This conclusion is somewhat misleading. In both experiments, there were numerous

11. Following Benoit and Krishna (1985), once we have a good and a bad subgame perfect equilibrium, we can construct many others. These two equilibrium paths however, seem to us the most salient and the most likely to be observed in the laboratory.

periods in which: (a) a subset of players played well beyond the safe strategy equilibrium; and (b) aggregate investment in Market 2 was beyond the safe investment of 40 tokens. What is different about these two experiments is that in many periods a sufficient number of players made small enough investments in Market 2 to offset the large investments by others. Second, in periods in which the groups invested beyond 40, a "good" draw led to a continuation of the experiment. Subjects in these experiments on average made Market 2 investments below the safe focal point of 40 tokens, but in no period did the groups reach the safe equilibrium of each player investing 5 tokens in Market 2.

We find these results to be even more striking than those obtained in Design I. In a decision environment with a well-defined probability of destruction, with a safe zone in which optimum rents could be obtained (and which included a "safe" Nash equilibrium path near the optimum): (1) in only two experiments did groups follow an investment pattern generally in the vicinity of the good subgame perfect equilibrium (17 of 32 periods strictly in the safe zone); and (2) in the remaining five experiments groups followed an investment pattern dispersed around the bad subgame perfect equilibrium. See Appendix B for period-by-period aggregate investment.

The first period behavior summarized in Figure 4 is revealing. Many players (43 of 64) did in fact play a strategy consistent with staying in the safe zone by investing 5 tokens or less in Market 2. However, each experiment had at least two players investing beyond the safe strategy. The resulting outcome led in subsequent periods to an increase in Market 2 investments by many players who initially followed the safe strategy.

## V. SUMMARY AND CONCLUSIONS

The results of these experiments are hardly cause for optimism with regard to CPR survival in environments where no institutions exist to foster cooperative behavior. In our experimental setting, when there is a nonnegligible probability of destruction, the CPR is in every case destroyed and, in most cases, rather quickly. The consequence of this destruction is a significant loss in rents. Even when there is a focal point Nash equilibrium which is completely safe and yields near optimal rents, subjects do not stabilize at this equilibrium.

The time dependence problem our subjects face is far simpler than those faced in naturally occurring renewable resources. In fisheries, for instance, not only is there a clear and present danger of extinction, but also, the one period payoff functions fluctuate wildly. As discussed by Allen and McGlade (1987), these fluctuations are driven by both economic and biological forces. On the economic side, market prices vary. On the biological side, population dynamics are much more complex than assumed in standard bionomic models. In such models, extinction is a limit which is approached slowly, while in reality, many biological species have a population dynamic that is characterized by sudden extinction. Our design captures this feature of sudden extinction, without recourse to other nonstationarities. In the presence of naturally occurring nonstationarities, the task of learning the payoff functions, much less best responses, is formidable. In this sense, our designs give survival its best shot. In the time it takes to learn in natural settings (void of institutions designed to foster cooperation) the resource may already be destroyed.

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## APPENDIX A
## EXPERIMENT ANNOUNCEMENTS

### ADDITIONAL INSTRUCTIONS - DESIGN I

1) Each participant will be paid one half of his/her earnings at the conclusion of the experiment.

2) The experiment will continue for up to 20 rounds.

3) The actual number of periods in the experiment depends on the overall group investment in Market 2. After each round, a random drawing will occur to determine if the experiment will continue to the next round.

   a) For every token invested in Market 2 by any participant, the probability of ending the experiment increases by one-half percent. For example:

   - If the group invests 50 tokens total in Market 2, the probability of ending the experiment is 25%.

   - If the group invests 21 tokens total in Market 2, the probability of ending the experiment is 10.5%.

   - If the group invests all 200 tokens in Market 2, the experiment automatically ends.

   b) The drawing at the end of each round works as follows:

   - A single card will be drawn randomly from a deck of 100 cards numbered from 1 to 100.

   - If the number on the card is equal to or below the probability of ending the experiment for that round (as determined by the group investment in that round) the experiment ends. Otherwise the experiment continues to the next round.

4) An Illustration: Assume each of the 8 members of the group invested 5 tokens in Market 2 (for a total of 40 tokens). The probability of ending the experiment would be 20%. If the card randomly drawn had a value of 20 or less the experiment would end. If the card drawn had a value of 21 or more the experiment would continue to the next round.

ADDITIONAL INSTRUCTIONS - DESIGN II

1) Each participant will be paid one half of his/her earnings at the conclusion of the experiment.

2) The experiment will continue for <u>up to</u> 20 rounds.

3) The actual number of periods in the experiment depends on the overall group investment in Market 2. After each round, a random drawing will occur to determine if the experiment will continue to the next round.

   a) If the group invests 40 tokens or less in Market 2, the experiment automatically goes to the next round. (There is no drawing to determine if the experiment ends.)

   b) If the group invests 41 tokens in Market 2, the probability of ending the experiment is <u>20.5%</u>.

   c) If the group invests more than 40 tokens in Market 2, the probability of ending the experiment increases by <u>one-half</u> percent for each token invested in Market 2 by any participant. For example:

   - If the group invests <u>50</u> tokens total in Market 2, the probability of ending the experiment is <u>25%.</u>

   - If the group invests <u>101</u> tokens total in Market 2, the probability of ending the experiment is <u>55.5%</u>

   - If the group invests all <u>200</u> tokens in Market 2, the experiment automatically ends.

   b) The drawing at the end of each round works as follows:

   - A single card will be drawn randomly from a deck of 100 cards numbered from 1 to 100.

   - If the number on the card is equal to or below the probability of ending the experiment for that round (as determined by the group investment in that round) the experiment ends. Otherwise the experiment continues to the next round.

4) An Illustration: Assume each of the 8 members of the group invested 6 tokens in Market 2 (for a total of 48 tokens). The probability of ending the experiment would be 24%. If the card randomly drawn had a value of 24 or less the experiment would end. If the card drawn had a value of 25 or more the experiment would continue to the next round.

5) Remember, if the group invests 40 tokens or less in Market 2, the probability of ending the experiment is zero. The experiment automatically proceeds to the next round.

## APPENDIX B

### ACROSS PERIOD BEHAVIOR: TOKENS INVESTED IN MARKET 2

| | PERIOD | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| **BASELINE** | | | | | | | | | | | | | | | | | | | | |
| **MEAN** | 92 | 74 | 74 | 66 | 71 | 79 | 72 | 73 | 75 | 63 | 64 | 67 | 75 | 67 | 69 | 67 | 65 | 61 | 65 | 68 |
| **DESIGN I** | | | | | | | | | | | | | | | | | | | | |
| **EXPERIMENT 1** | 36 | 36 | 44 | 25 | | | | | | | | | | | | | | | | |
| **EXPERIMENT 2** | 80 | 32 | 51 | 57 | | | | | | | | | | | | | | | | |
| **EXPERIMENT 3** | 49 | 60 | 72 | | | | | | | | | | | | | | | | | |
| **EXPERIMENT 4** | 47 | 45 | 54 | 51 | 61 | 60 | | | | | | | | | | | | | | |
| **EXPERIMENT 5** | 70 | 60 | | | | | | | | | | | | | | | | | | |
| **DESIGN II** | | | | | | | | | | | | | | | | | | | | |
| **EXPERIMENT 1** | 45 | 40 | 41 | 44 | 36 | 51 | | | | | | | | | | | | | | |
| **EXPERIMENT 2** | 62 | 59 | 58 | | | | | | | | | | | | | | | | | |
| **EXPERIMENT 3** | 78 | 45 | 63 | 64 | 67 | | | | | | | | | | | | | | | |
| **EXPERIMENT 4** | 58 | 75 | 87 | 44 | 46 | 58 | | | | | | | | | | | | | | |
| **EXPERIMENT 5** | 50 | 21 | 28 | 45 | 30 | 28 | 38 | 36 | 34 | 38 | 44 | 50 | 42 | 40 | 37 | 42 | 42 | | | |
| **EXPERIMENT 6** | 41 | 30 | 32 | 55 | 32 | 45 | 43 | 28 | 30 | 41 | 36 | 40 | 37 | 36 | 43 | | | | | |
| **EXPERIMENT 7** | 55 | 50 | | | | | | | | | | | | | | | | | | |

Table 1

EXPERIMENTAL DESIGN BASELINE
Parameters for a Given Decision Period

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

* $\Sigma x_i$ = 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.

** Subjects were paid in cash one-half of their PLATO earnings. Amounts shown are potential cash payoffs.

Table 2

DESCRIPTIVE STATISTICS: BASELINE
PERCENTAGE OF MAXIMUM RENTS ACCRUED
(mean - standard deviation - range)*

| | | | |
|---|---|---|---|
| 1X25: | 5.32, | 65.28, | (-160 to 75) |
| 2X25: | -28.22, | 106.40, | (-382 to 97) |
| 3X25: | 13.41, | 50.97, | (-109 to 63) |
| Pooled: | -3.16, | 78.64, | (-382 to 97) |

* All decision periods are used in calculating the descriptive statistics. All experiments lasted 25 periods.

Table 3

DYNAMIC PROGRAMMING PATHS, DESIGN I

| | Optimum Path | | Subgame Perfect Equilibrium Path | |
|---|---|---|---|---|
| Periods Remaining | Aggregate Investment | Optimal Value Per Capita | Aggregate Investment | Equilibrium Value |
| 1 | 36.0 | 246 | 64.0 | 141 |
| 2 | 16.0 | 380 | 61.5 | 243 |
| 3 | 6.0 | 506 | 59.7 | 318 |
| 4 | 0.0 | 631 | 58.3 | 375 |
| 5 | 0.0 | 756 | 57.3 | 419 |
| 6 | 0.0 | 881 | 56.6 | 453 |
| 7 | 0.0 | 1006 | 55.9 | 479 |
| 8 | 0.0 | 1131 | 55.5 | 500 |
| 9 | 0.0 | 1256 | 55.1 | 516 |
| 10 | 0.0 | 1381 | 54.8 | 529 |
| 11 | 0.0 | 1506 | 54.6 | 539 |
| 12 | 0.0 | 1631 | 54.4 | 547 |
| 13 | 0.0 | 1756 | 54.3 | 554 |
| 14 | 0.0 | 1881 | 54.2 | 559 |
| 15 | 0.0 | 2006 | 54.1 | 563 |
| 16 | 0.0 | 2131 | 54.0 | 566 |
| 17 | 0.0 | 2256 | 53.9 | 569 |
| 18 | 0.0 | 2381 | 53.8 | 571 |
| 19 | 0.0 | 2506 | 53.8 | 573 |
| 20 | 0.0 | 2631 | 53.8 | 574 |

Table 4

CPR INVESTMENTS IN DESIGN I EXPERIMENTS

| EXPERIMENT | AVERAGE TOKENS INVESTED | NUMBER OF PERIODS BEFORE DESTRUCTION | PERCENTAGE OF OPTIMAL INCOME EARNED |
|---|---|---|---|
| 1 | 35.25 | 4 | 18.8 |
| 2 | 55.00 | 4 | 22.06 |
| 3 | 60.33 | 3 | 16.45 |
| 4 | 53.00 | 6 | 35.43 |
| 5X | 65.00 | 2 | 10.52 |

NOTE: 1) COLUMN 4 - ACTUAL INCOME EARNED/ INCOME USING OPTIMAL PATH
2) X - SUBJECTS EXPERIENCED IN A DESTRUCTION EXPERIMENT

Table 5

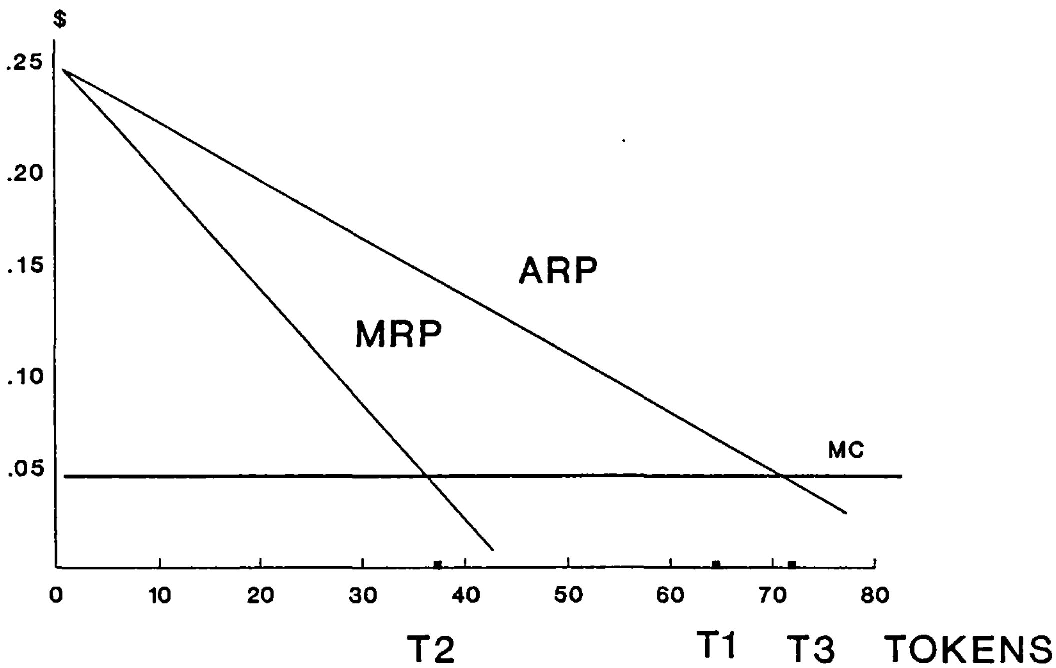
CPR INVESTMENTS IN DESIGN II EXPERIMENTS

| EXPERIMENT | AVERAGE TOKENS INVESTED | NUMBER OF PERIODS BEFORE DESTRUCTION | PERCENTAGE OF OPTIMAL INCOME EARNED |
|---|---|---|---|
| 1 | 42.96 | 6 | 29.59 |
| 2 | 59.68 | 3 | 13.39 |
| 3 | 63.41 | 5 | 20.91 |
| 4X | 61.34 | 6 | 25.02 |
| 5 | 37.95 | 17 | 83.94 |
| 6 | 37.95 | 15 | 74.22 |
| 7 | 52.48 | 2 | 9.52 |

NOTE: 1) COLUMN 4 - ACTUAL INCOME EARNED/ INCOME USING OPTIMAL PATH
2) X - SUBJECTS EXPERIENCED IN A DESTRUCTION EXPERIMENT

# FIGURE 1

THEORETICAL PREDICTIONS: BASELINE DESIGN




PREDICTIONS: T1=64; T2=36; T3=72