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PROBABILISTIC DESTRUCTION OF COMMON POOL RESOURCES: EXPERIMENTAL EVIDENCE

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ABSTRACT

This paper uses a game theoretic model of a common pool resources to investigate whether the possibility of destroying the resource significantly affects choice behavior in the laboratory. When subgame perfection involves a significant probability of destruction, the common pool resource is in every case destroyed and, in most cases, rather quickly. Even when there is a 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 efficiency.

I. INTRODUCTION

Common-pool resources (CPRs) are defined to be natural or man-made resources in which: (a) yield is subtractable and (b) exclusion is nontrivial (but not necessarily impossible). Examples of CPRs include open seas fisheries, unfenced grazing range, and groundwater basins. Scholars such as Gordon (1954) and Hardin (1968) argue that when individuals exploit CPRs, each is driven by an inexorable logic to withdraw more of the resource units (or invest less in maintenance of the resource) than is Pareto optimal. Rents are dissipated.[1]

Although the dissipation of rent from a CPR is a serious economic problem, even more urgent is the problem of the destruction of the resource. Many CPRs are fragile, and human exploitation can lead to destruction. A fishery is a simple example. If all the fish of a species are taken in a single period, the species becomes extinct and the CPR is destroyed. A more subtle example involving a geothermal CPR is given by Kerr (1991). The Geysers is a geothermal power source in Northern California which has been exploited since 1960. Although grave uncertainties surround the underground structure of this resource, it is known to be fed by groundwater. This, when combined with geothermal heat, produces steam energy harnessed by electrical turbines at the surface. Due to expansion of electrical generating capacity, the safe yield of steam has been exceeded. The Geysers are rapidly drying up, and are almost certain to have been destroyed by the end of the century. Similar considerations apply to global commons, such as the build up of carbon dioxide in the earth's atmosphere. Trace levels of this gas do not affect life on earth. Current models of the atmosphere leave a wide zone of uncertainty as to what happens when carbon dioxide builds up in the atmosphere (Reilly etal., 1987). At some level, as on the planet Venus, the carbon dioxide concentration destroys the biosphere.

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

A range of safe yield underlies each of these classes of CPRs. A natural regeneration process is present that implies a range of exploitation in which the probability of destruction is zero. When the safe yield is surpassed, the resource faces probabilistic destruction. Indeed, at high enough levels of economic activity, the resource is destroyed with certainty. The economic question is the tradeoff between jeopardizing the life of the resource and earning rents from it. It is the behavioral response of highly motivated decision makers to this economic dilemma that we focus on in this paper.

We frame the model and the laboratory CPR as noncooperative games. These games have many Nash equilibria. We adopt as our refinement subgame perfection. When there are multiple subgame perfect equilibria, we select among them using the principle of payoff dominance (Harsanyi and Selten, 1988). We have two primary treatments, depending upon whether the safe zone consists of a single point or an interval. Our primary results are that: (1) if the safe zone consists of a single point, the resource is rapidly destroyed in accordance with subgame perfect equilibrium; (2) if the safe zone is an interval, then group behavior in some instances tends to focus on the best available equilibrium, but in general this equilibrium cannot be sustained and the resource is destroyed. These results show how valuable agreement among appropriators of a CPR can be, not only in capturing rents but also in saving the CPR from destruction.

The paper *is* organized as follows. The next section models the one period CPR and the repeated game with probabilistic destruction. Section III describes our experimental design and section IV, our experimental results. The final section offers a conclusion and open questions for further research.

II. MODEL OF A DESTRUCTIBLE CPR

A. The CPR Constituent Game

We will first specify the class of constituent CPR games from which we drawn our designs. 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 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. The marginal payoff of the outside activity is w. 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 all resources in the CPR the outcome is counterproductive [$F'(ne) < 0$]. Thus, the yield from the CPR reaches a maximum when individuals invest some but not all of their endowments in the CPR.

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:

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

(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:

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

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

There are several ways to interpret an equilibrium condition such as (2). One is in terms of disequilibrium, namely that any behavior not satisfying (2) will not persist over time, but will disappear. A second interpretation is in terms of equilibrium, namely that once behavior satisfies (2) that behavior persists over time. Neither of these interpretations says anything about the dynamics of behavioral change. A third and much stronger dynamic interpretation (2) is in terms of evolutionary stability. If behavior is being selected for according to the replicator equations, then (2) characterizes the unique dynamic stable equilibrium of the associated dynamical system (Hofbauer and Sigmund 1988).[2] A final interpretation is as a limited access CPR (see, for example, Clark 1980; Cornes and Sandler 1986; and Negri 1989).[3]

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),

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

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:

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

[2] The proof of this result is available upon request.

[3] Consistent Conjectural Variations Equilibria may provide a useful method for a detailed analysis of individual subject behavior in these experiments. See Mason, et al. (1988) for a discussion of consistent conjectures equilibria for the CPR experiment. See Walker, Gardner, and Ostrom (1991) for a discussion of several alternative theories that could be used to provide a solution to the core, constituent game.

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.

B. Finite Deterministic Repetition of the Constituent Game

Denote the constituent game by X and let X be played a finite number of times T. Let t index the number of periods left before play ends, t=1,...,T. Let $x_t=(x_{1t},...,x_{nt})$ be a vector of individual decisions at time t. An optimal return function defined recursively for player i, f_{it}, is given by:

$$f_{it}(x_t) = \max_{x_{it}} \; u_{it}(x_t) + f_{i,t-1}(x_{t-1}) \qquad (5)$$

where u_{it} is the contemporaneous return function for player i at time t as in (1), $f_{i,t-1}$ is the optimal return function for the next period, and $f_{i0}=0$. The solution to (5) for all players i and all times t is a subgame perfect equilibrium of X finitely repeated. If X has a unique equilibrium, then finitely repeated X has a unique subgame perfect equilibrium (Selten, 1971). Thus (5) has a unique solution given by the solution of (2) in each period t.

C. Probabilistic Repetition of the Constituent Game

We model probabilistic destruction of the CPR as a 1-period hazard rate depending upon the current period's decisions. Formerly, the decision environment is a finitely repeated game with an endogenous continuation probability $p_t(x_t)$. Define LUB as the lowest upper bound on exploitation with probability 1 destruction and GLB as the greatest lower bound with probability 0 destruction. We specify the continuation probability as follows:

$$p_t(x_t) = \begin{cases} 0 & \text{if } \Sigma x_{it} \geq \text{LUB} \\ p(\Sigma x_{it}) & \text{if GLB} < \Sigma x_{it} < \text{LUB} \\ 1 & \text{if } \Sigma x_{it} \leq \text{GLB} \end{cases} \qquad (6)$$

In the event $p_t(x_t) = 0$, the resource has been destroyed and play ends. The probability of destruction depends on aggregate exploitation through Σx_{it}, with $p_t(x_t)$ a nonnegative decreasing function of its argument. One has $0 \leq GLB < LUB$. GLB represents the safe yield and the interval [0,GLB] the safe zone.[4]

In the presence of probabilistic continuation, the optimal return function is amended to :

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

Since utility is linear, specification (7) implies risk neutrality on the part of all players. As before, a solution to the recursive equation (7) is a subgame perfect equilibrium. It is important to note even if the constituent game has a unique Nash equilibrium, (7) may have multiple solutions.

III. THE EXPERIMENTAL DESIGN

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

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

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

For this quadratic specification, one has from (4) that the group optimal investment satisfies $\Sigma x_i = (a-w)/2b$. The CPR yields 0% on net when investment is twice as large as optimal, $\Sigma x_i = (a-w)/b$. Finally, from (2), the symmetric Nash equilibrium group investment is given by:

$$\Sigma x_i = (n/(n+1))(a-w)/b.$$

[4] As a referee correctly points out, specification (6) is restrictive. It would be more general to make the probability of destruction depend on the entire history of the game. However, we view the ensuing complication, although interesting, as not a best starting point for our exploration.

This level of investment is between maximal net yield and zero net yield, approaching the latter as n gets large. One additional constraint that arises in a laboratory setting is that the x_i be integer-valued. This is accomplished by choosing the parameters a, b, d, and w in such a way that the predictions associated with Σx_i are all integer valued.

In particular, we use the parameters shown in Table 1. A group investment of 36 tokens yields the optimal level of investment. The symmetric constituent game has a unique Nash equilibrium with each subject investing 8 tokens in Market 2. At the Nash equilibrium, subjects earn approximately 39.5% of maximum net yield from the CPR.

The experiments reported in this paper used subjects drawn from the undergraduate population at Indiana University. Students were volunteers recruited 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" environment and that the money they earned would be dependent upon their own investment decisions and those of the others in their experimental group. All experiments were conducted on the NOVANET computer system at IU. The computer facilitates the accounting procedures involved in the experiment, enhances across experimental/subject control, and allows for minimal experimenter involvement.

Subjects can be viewed as facing the constituent game to which a probabilistic structure has been attached. In the constituent game the decision task 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. 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.[5]

Destruction Design I

In Design I destruction experiments the decision tasked faced by our subjects is amended in the following manner:[6]

> *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 panicipant, 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.*

Thus the parameterization was GLB=0, LUB=200, and the probability of continuation (6) was:

$$p_t(x_t) = 1-(\Sigma x_{it}/200) \qquad (8)$$

The safe zone consisted of a single point, zero exploitation. The optimal solution can be found by solving (5) with a single player in control of all resources. Similarly, the subgame perfect equilibrium can be found by solving (5) and exploiting symmetry. In Table 2, we present these solutions for the entire life of the resource, given that T=20.[7] Three features of this symmetric subgame perfect

[5] At the end of all experiments, subjects were paid privately (in cash) their individual earnings. All subjects in the destruction experiments had participated previously in an experiment using the constituent game environment with no destruction. Subjects in the destruction experiments were recruited randomly from this pool of experienced subjects to insure that no prior experimental group was brought back intact. Walker, Ostrom, and Gardner (1990 and 1991) provide a detailed account of behavior in the constituent game environment. Complete instructions are available from the authors.

[6] 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. This information in the destruction experiments makes the optimization task tractable.

[7] For periods 6-17, all values change monotonically except for optimal investment which remains at 0.

equilibrium path should be noted. In contrast to the optimal path, where only in the last 3 periods is there a positive probability of destruction, the subgame perfect equilibrium path has a positive and growing probability of destruction throughout the experiment. At the outset, the 1-period destruction probability is approximately 27 percent at the subgame equilibrium, and it rises to 32 percent by the end. With 1-period hazard rates this high, it is unlikely (probability less than .05) that the resource will survive 10 periods. 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(574) cents), as opposed to over $200 at the optimum. Finally, individual value stabilizes at 574 for infinitely long experiments. Thus, T=20 is theoretically long enough to yield steady state behavior consistent with the optimal value function.

Destruction Design II

Our Design I *is* unforgiving in the sense that any investment in the CPR leads to a positive 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 is 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.*

Thus the parameterization was GLB=40, LUB=200, and the probability of continuation was given by (8) on the open interval (40,200). Design II gives subjects a large safe zone [0,40] in which to exploit the resource.[8] Since the safe zone includes the one period optimal solution, a coordinating rational agent would play 36 tokens each period to maximize rents.

Subgame perfect Nash equilibria can be found by applying dynamic programming to (7). First, note that the Nash equilibrium path described for Design I remains an equilibrium path for Design II, since this path never enters the safe zone. There is, however, another equilibrium path in Design II which is better in payoff space. This equilibrium path invests 64 tokens in Market 2 with one period to go, but later switches to GLB at some critical time. That 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 in the destruction zone 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. Repeating the above calculations for t=3, 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. Since expected future value grows with time remaining, once this backward induction path enters the safe zone, it stays there.[9] Indeed, this equilibrium path with an efficiency of 92% is nearly as good as the optimum path for Design II. The optimal path and the best subgame perfect equilibrium path are shown in Table 3. There is a

[8] 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.

[9] 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 likely to be observed in the laboratory.

dramatic difference in payoffs between the good equilibrium and the bad one; this environment gives a clear "equilibrium focal" point for behavior. By investing 40 tokens in every period the group receives very close to optimal rents (97 percent) and runs no risk of ending the experiment.

IV. EXPERIMENTAL RESULTS

Our experimental results are summarized by first examining aggregate investments. The aggregate results of all 12 experiments are presented in Table 4. All five Design I experiments yielded investment efficiencies below 36%. The longest experiment lasted 6 periods. The average efficiency over all Design I experiments was 21%, as predicted by subgame perfect equilibrium. These results are striking. In a decision environment with a well-defined probability and significant opportunity costs of destruction, efficiency is very low and the resource is quickly destroyed. Individual and group investments in Market 2 are well beyond optimum levels, with an average investment of 47.1 tokens per period. 32% of all group outcomes lie in the interval [54-64] containing the subgame perfect equilibrium path. 53% lie below 54 and 16% lie above 64.

In five of the seven Design II experiments, destruction occurred early and efficiency was below 30%. Of these five experiments, the longest lasted 6 periods. In two Design II experiments, destruction did not occur until late in the experiment (rounds 15 and 17) and efficiencies were high (74% and 84%). Overall average efficiency was 37% in Design II, a significant increase over Design I. Average investment in Market 2 fell to 45.9 tokens per period. It appears that in Design II the large safe zone did serve as a focal point for many subjects. This is borne out by the data displayed in Table 5. A Kolmogorov-Smirnov test shows a significant difference in the cumulative distribution of Market 2 investments in the two designs. The percentage of periods where Market 2 investment is less than or equal to 40 nearly doubles in Design II. We can also see this effect in the individual data, although it is less pronounced.

At the individual level the data for the two experiments which survived the longest present a mixed picture. There were numerous 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. Further, in periods in which the groups invested beyond 40, a "good" draw led to a continuation of the experiment. Subjects in these experiments made average Market 2 investments of 38 tokens, below the safe focal point of 40 tokens, but in no period did the groups reach the safe equilibrium of every player investing 5 tokens in Market 2.

These results are 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 subgame perfect 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.

Figure 1 summarizes first period individual behavior. The top panel displays observations from the Design I experiments. Only 2 of 40 individuals play the safe strategy of investing 0 tokens in Market 2. Further, the frequency of players investing 6 or more tokens in Market 2 is high (21 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 very 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, however, investments began to increase after period 2.

The first period behavior of Design II is summarized in the lower panel of Figure 1. 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. There will usually be considerable uncertainty surrounding the safe zone (is there one, how large is it, etc.) As a result, there will be uncertainty about the best policy to improve the extremely low efficiencies. In the time it takes to learn in natural settings (void of institutions designed to foster cooperation) the resource may already be destroyed.

The behavior in this laboratory CPR environment adds additional evidence to field data regarding the need for well formulated and tested institutional changes designed to balance appropriation with natural regeneration. Our laboratory setting offers one possible environment for investigating alternative institutions. One institutional change currently under discussion appears in Malik, et.al.,1991. In deliberations over reauthorization of the U.S. Water Quality Act of 1983, one proposal involves the use of an environmental bond. Each period, appropriators post a bond of a determinate size, which they forfeit in the event that the CPR is destroyed (or some other well defined measure of overuse). Otherwise, the bond is retained for another period. In our laboratory environment, one can show that posting a bond the size of the steady state value in our Design I is theoretically enough to induce appropriators to preserve the CPR. A somewhat smaller bond is sufficient to move appropriators to the safe zone in Design II. Behaviorally, the mere fact of having to post a bond could serve to focus subjects on the safe zone, even if their behavior is only limitedly rational. The laboratory investigation of such institutional reforms is one direction for research we plan for the future.

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Table 1

Parameters for the Constituent Game

Number of Subjects	8
Individual Token Endowment	25
Production Function in cents: Mkt.2*	$23(\Sigma x_i)-.25(\Sigma x_i)^2$
Market 2 Return/unit of output in cents	1
Market 1 Return/unit of output in cents	5

* 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.

** Subjects were paid in cash one-half of their PLATO earnings.

Table 2
DYNAMIC PROGRAMMING PATHS, DESIGN I

	Optimum Path		Subgame Perfect Equilibrium Path	
Periods Remaining	Aggregate Investment	Optimal Value Per Capita in Cents	Aggregate Investment	Equilibrium Value in Cents
1	36.0	246	64.0	141
2	16.0	380	61.5	243
3	06.0	506	59.7	318
4	00.0	631	58.3	375
5	00.0	756	57.3	419
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
18	00.0	2381	53.8	571
19	00.0	2506	53.8	573
20	00.0	2631	53.8	574

Table 3
DYNAMIC PROGRAMMING PATHS, DESIGN II

	Optimum Path		Best Subgame Perfect Equilibrium Path	
Periods Remaining	Aggregate Investment	Optimal Value Per Capita in Cents	Aggregate Investment	Equilibrium Value in Cents
1	36.0	246	64.0	141
2	36.0	492	61.5	243
3	36.0	738	40.0	408
4	36.0	984	40.0	652
5	36.0	1230	40.0	896
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
18	36.0	4428	40.0	4068
19	36.0	4674	40.0	4312
20	36.0	4920	40.0	4556

Table 4

CPR INVESTMENTS IN DESTRUCTION EXPERIMENTS

EXPERIMENT	AVERAGE TOKENS INVESTED	NUMBER OF PERIODS BEFORE DESTRUCTION	PERCENTAGE OF OPTIMAL INCOME EARNED
DESIGN I			
1	35.25	4	18.80
2	55.00	4	22.06
3	60.33	3	16.45
4	53.00	6	35.43
5X	65.00	2	10.52
DESIGN II			
1	42.83	6	29.59
2	59.68	3	13.39
3	63.41	5	20.91
4X	61.34	6	25.02
5	37.94	17	83.94
6	37.93	15	74.22
7	52.50	2	9.52

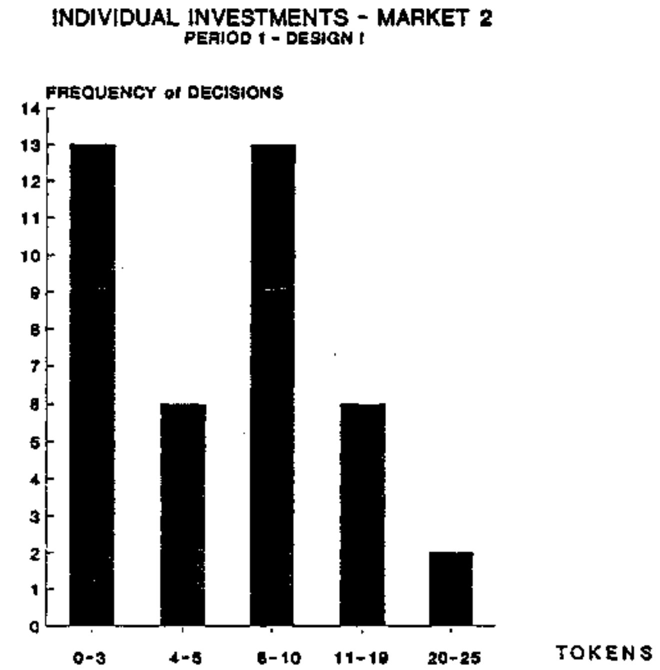
1) COLUMN 4 - ACTUAL INCOME EARNED/ INCOME USING OPTIMAL PATH
2) X - SUBJECTS EXPERIENCED IN A DESTRUCTION EXPERIMENT

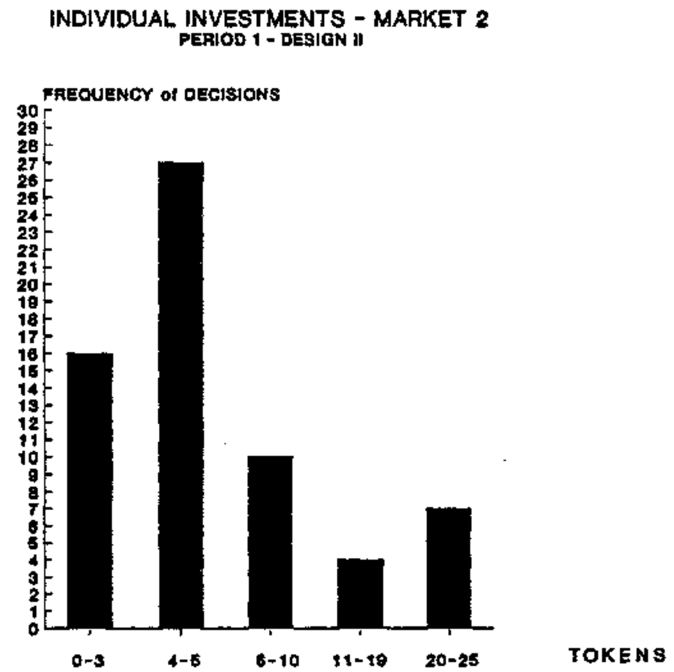
Table 5

CUMULATIVE INVESTMENTS IN MARKET 2: AGGREGATE AND INDIVIDUAL DATA

AGGREGATE	**$\Sigma x_i \leq 40$**	**41 TO 53**	**54 TO 64**	**> 64**	
DESIGN I	21%	32%	32%	16%	
DESIGN II	39%	35%	19%	6%	
INDIVIDUAL	**$x_i \leq 5$**	**$6 \leq x_i \leq 10$**	**$11 \leq x_i \leq 15$**	**$16 \leq x_i \leq 19$**	$20 \leq x_i \leq 25$
DESIGN I	54%	30%	10%	2%	4%
DESIGN II	66%	22%	8%	2%	2%

FIGURE 1


INDIVIDUAL INVESTMENTS - MARKET 2
PERIOD 1 - DESIGN I
FREQUENCY of DECISIONS
0-3
4-5
6-10
11-19
20-25
TOKENS


INDIVIDUAL INVESTMENTS - MARKET 2
PERIOD 1 - DESIGN II
FREQUENCY of DECISIONS
0-3
4-5
6-10
11-19
20-25
TOKENS