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RENT-DISSIPATION IN COMMON-POOL RESOURCE ENVIRONMENTS: EXPERIMENTAL EVIDENCE

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ABSTRACT

This paper examines the resource environment classified as a common-pool resource. The intent is to highlight and more carefully classify the specific forms of behavioral problems encountered in this resource allocation environment, with an emphasis on the particular allocation problem known commonly as "rent dissipation." We present evidence from laboratory experiments designed to investigate the robustness of theoretical models of rent dissipation in such environments.

Following the theoretical work of such authors as Scott Gordon (1954), we investigate the strength of theoretical models which predict that users of common-pool resources will appropriate units from the resource at a rate which exceeds the point at which marginal returns equal marginal extraction costs. The logic of such models argues that appropriators will ignore the production externalites of their own appropriation and focus only on average returns from the resource. Following this argument, appropriation will take place at a level in which all rents are dissipated.

Our experimental results present evidence from a behavioral investment environment designed to capture the key theoretical assumptions of the rent dissipation models. We offer evidence related to the extent of rent dissipation as related to subject experience in the environment, the form of the production technology of the common-pool resource, and the size of the appropriation group.

I. INTRODUCTION

In the literature devoted to optimal resource allocation, there exists considerable theoretical and field work investigating the social dilemma faced by individuals in resource environments defined as open access common pool resources (CPRs).[1] The generally accepted premise is that, void of imposing private property rights or a central planner, users of such resources will over invest in appropriation from the resource, leading to the inefficient dissipation of economic rents and possible resource destruction. This paper investigates actual choice behavior in a decision environment designed to capture the resource properties assumed in accepted theoretical models which focus on this dilemma[2]. The research uses the methodology of experimental economics to induce the appropriate incentive structure and institutional framework on resource users. Our investigation is designed to test the accuracy and robustness, at the individual and aggregate levels, of the standard predictions of the theoretical models.

The formal modelling and description of rent dissipation in common pool resources traces its roots to the seminal paper by Scott Gordon (1954). Prior to Gordon's analysis, discussions on the appropriation from commonly held resources focused primarily on the biological issue of the size of the resource stock. Scott's work redirected the focus to the problem of optimal appropriation, where the goal is economic efficiency. Briefly, the behavioral hypothesis described by Gordon can be summarized as follows. Individuals appropriate a resource in which marginal changes in appropriation levels have external production effects on the production relationship faced by all other users. More precisely, Gordon assumes that increases in levels of appropriation by individual users lowers the marginal physical product to investment by all users. Given the external nature of this effect, however, individual users are assumed to ignore the effects and focus only on average returns from investment. Such behavior by all individuals leads to a level of appropriation in which average revenue product of increased appropriation equals marginal opportunity costs. Thus, the resource is "mined" at a level beyond the economically efficient point at which marginal revenue product equals marginal opportunity cost (economics rents are dissipated). Note that it does not immediately follow that such behavior leads to the secondary issue of destruction of a renewable resource. This latter prediction requires further constraints on the specific relationship between the reproductive nature of the resource and the level of appropriation. This paper focuses directly on the issue of over appropriation itself.

The theoretical framework laid out by Gordon has been extended by others such as Smith (1968) and Clark (1976). There have also been numerous "case studies" directed toward estimating the degree to which open access resources are mined at a level predicted by the theoretical models (eg. Alexander (1982), Agnello and Donnelly(1975), Bell (1972), and Johnson and Libecap (1982)). However, field studies are limited by the extent to which the optimal level of appropriation and actual appropriation are calculable and observable. Further, such studies are limited by the extent to which the observer is able to infer the consequences of parametric changes in the behavioral environment. The choice environment described in this experimental study is designed to provide a baseline environment for testing the behavioral accuracy of CPR theoretical models and for investigating the linkages between individual behavior and environmental (parametric) conditions. The baseline design creates an environment where no institutional configuration has been created to monitor or limit the amount of investment. Thus, the design captures the essence of open access.

The paper proceeds as follows. Section II describes the actual choice environment faced by experimental subjects. Given this framework, section III focuses on the specific nature of several classes of theoretical predictions. In section IV, we summarize in descriptive form the results of our experiments and present formal statistical tests of the theoretical hypotheses. Section V includes a description of a second set of experiments designed to investigate the robustness of our initial design. In section VI, we close with a summary of our results and concluding comments.

II. EXPERIMENTAL ENVIRONMENT

A. Subjects and the Experimental Setting

The experiments reported in this paper were conducted using subjects drawn from the undergraduate population at Indiana University. Students were volunteers recruited primarily from principles of economics classes. Prior to recruiting, potential volunteers were given a brief explanation in which they were told only that they would be making decisions in a "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 PLATO computer system at IU. The use of the computer facilitates the accounting procedures involved in the experiment, enhances across experiment control in experimental procedures, and allows for minimal experimenter interaction.

B. The Choice Environment

At the beginning of each experimental session, subjects were told that 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 from the experiment. Subjects then proceeded to go through, at their own pace, a set of instructions that described the investment decisions.

Subjects were instructed that each period they would be endowed with a given number of tokens (e^). Each period they were to invest their endowment 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 investment for the group 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. Figure 1 displays the actual information subjects saw as summary information in the experiment. The instructions were written to describe each level of information displayed in Figure 1. Subjects knew with certainty the total number of decision makers in the group, total group tokens, and that endowments were identical. They did not know the actual number of decision periods that would constitute the experiment. Subjects were separated by blinders and were not allowed to communicate.

Our initial set of 18 "baseline" experiments are divided into two parametric conditions (high and low pay) shown in Table 1. Conditions were constant within a given experiment. All experiments were conducted for at least 20 decision periods (no more than 25). As shown in Table 1, our experimental design called for inexperienced and experienced groups. Experienced groups included subjects who had participated in any one of the previous inexperienced runs. No experienced group was comprised of an inexperienced group held intact.

III. THEORETICAL PREDICTIONS

Given our specific experimental design, we can proceed to examine possible theoretical predictions for this choice environment. The

FIGURE 1

INSTRUCTIONS - SUMMARY INFORMATION

UNITS PRODUCED AND CASH RETURN FROM INVESTMENTS IN MARKET 2
commodity 2 value per unit = $0.01

Tokens Invested by Group	Units of Commodity 2 Produced	Total Group Return	Average Return per Token	Additional Return per Token
8	181	$ 1.81	$ 0.23	$ 0.23
16	323	$ 3.23	$ 0.20	$ 0.18
24	427	$ 4.27	$ 0.18	$ 0.13
32	493	$ 4.93	$ 0.15	$ 0.08
40	520	$ 5.20	$ 0.13	$ 0.03
48	509	$ 5.09	$ 0.11	$-0.01
56	459	$ 4.59	$ 0.08	$-0.06
64	371	$ 3.71	$ 0.06	$-0.11
72	245	$ 2.45	$ 0.03	$-0.16
80	80	$ 0.80	$ 0.01	$-0.21

The table shown above displays information on investments in Market 2 at various levels of group investment. Your return from Market 2 depends on what percentage of the total group investment is made by you.

Market 1 returns you one unit of commodity 1 for each token you invest in Market 1. Each unit of commodity 1 pays you $ 0.05.

Press -BACK-

TABLE 1

EXPERIMENTAL DESIGN
Parameters for a Given Decision Period

Experiment Type:	High Pay	Low Pay
Inexperienced Experiments	4	6
Experienced Experiments	4	4
Number of Subjects*	8	8
Individual Token Endowment	10	10
Production Function: Mkt.2**	$25(\Sigma x_i)-.30(\Sigma x_i)^2$	$15(\Sigma x_i)-.15(\Sigma x_i)^2$
Market 2 Return/unit of output	\$.01	\$.01
Market 1 Return/unit of output	\$.05	\$.05
Maximum Group Rents	\$.92	\$.50

* In two experiments (one inexperienced and one experienced) we had only 7 subjects. In these experiments subjects received and endowment of 12 tokens.

** Σx_i = the total number of tokens invested by the group in Market 2. The produciton function shows the number of units of output produced in market 2 for each level of tokens invested in market 2.

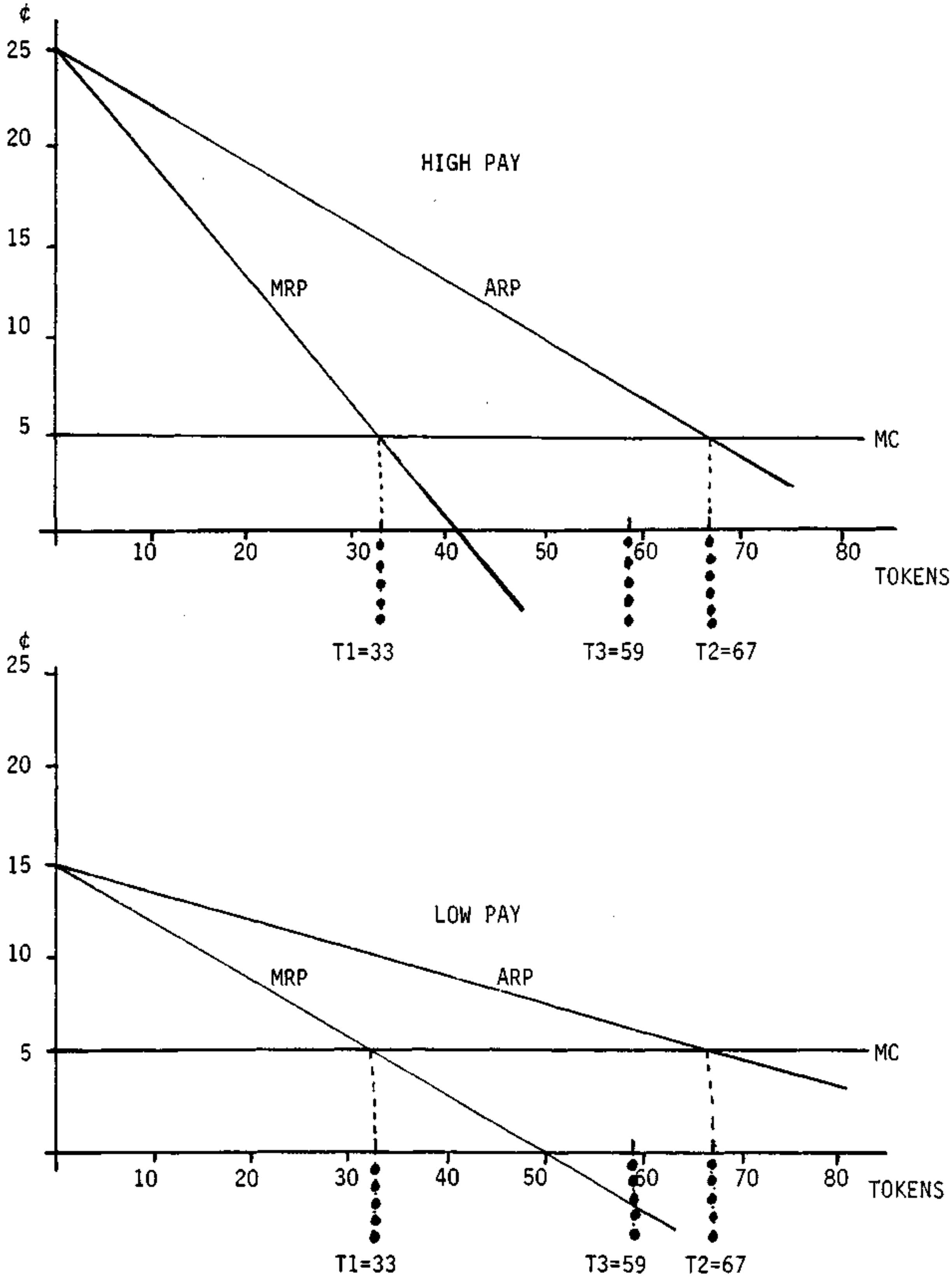
predictions are classified into three principle areas: 1) group optimality (maximum rents), 2) Nash equilibrium, and 3) complete rent dissipation. Figure 2 illustrates group behavior which would be consistent with the theoretical predictions.

Our two parameterizations were designed to allow for differences in potential payoffs, while holding the token allocations predicted by the theory for group optimality and zero rents approximately constant. As noted in Figure 2, a group investment of 33 tokens yields a level of investment at which MRP = MC and thus maximum rents (denoted Tl) . Conversely, a group investment of 67 tokens yields a level of investment at which ARP - MC and thus zero rents from Market 2 (denoted T2). The research hypothesis behind our two parameterizations was that the degree and speed of rent dissipation might be inversely related with the degree to which MRP fell as investment in market 2 increased. That is, if decision makers were aware of marginal production effects, we would expect them to be <u>more</u> aware of these effects in a design in which marginal changes were greater. As shown in Figure 2, MRP falls twice as fast in the high pay condition as in the low pay condition. Further, note that given our parameterizations, the losses from full rent dissipation are greater in the high payoff condition. Both of these attributes could have the impact of hindering full rent dissipation. Finally, multiple payoff conditions for our baseline experiments leads to more information regarding the internal validity of our research results.

Given the nature of our production functions for market 2 and the fact that subjects have multiple tokens to invest, there exist a set

FIGURE 2

MARKET INVESTMENT RETURNS
HIGH PAY AND LOW PAY DESIGNS



of Nash equilibria. These equilibria can be described as follows. Consider first the high pay parameterization. The strategy set for each player is $x_i \in \{0,1,2,\ldots,10\}$, where x_i denotes the number of tokens in market 2. The payoff for player i $h_i(x)$,in cents, is:

$$h_i(x) = \begin{cases} 50 & \text{if } x_i = 0 \\ 5(10-x_i) + (x_i/\Sigma x_i)(25\,\Sigma x_i - .3(\Sigma x)^2) & \text{if } x_i > 0 \end{cases}$$

where $x = (x_1,\ldots,x_8)$ is the vector of strategies of all players. This symmetric game has 57 Nash equilibria. 56 of these are asymmetric and in pure strategies, with $\Sigma x_i = 59$ (approximately 41% of rents possible from market 2)[3]. These are generated by having 5 players play $x_i = 7$ and 3 players play $x_i = 8$. The game also has a symmetric Nash equilibrium in mixed strategies, with $E(\Sigma x_i) = 59$ and $Var(\Sigma x_i) = 1.7$ (denoted as T3 in Figure 2). This equilibrium is generated by each player playing $x_i = 7$ with probability .62 and $x_i = 8$ with probability .38. It is this symmetric mixed strategy that equilibrium selection theory (Harsanyi & Selten, 1988) predicts will be played.

In the low pay parameterization, the strategy sets are the same but the payoff functions are now:

$$h_i(x) = \begin{cases} 50 & \text{if } x_i = 0 \\ 5(10-x_i) + (x_i/\Sigma x_i)(15\,\Sigma x_i - .15(\Sigma x_i)^2) & \text{if } x_i > 0. \end{cases}$$

Despite the lower payoff potential, this game has qualitatively the same set of Nash equilibria as the previous game. In particular, its symmetric Nash equilibrium continues to have the same mean and variance, to 10^{-1} accuracy. As in the high pay design, the investment of 59 tokens would earn the group approximately 41% of possible rents from market 2.

In designing any experiment there is always a question of what is the most acceptable way of operationalizing the theoretical environment to be examined. Most theoretical models are incomplete with respect to the exact form and level of information that should be available to decision makers, as well as the specific institutional arrangement for translating subjects choices into outcomes. In fact, it is such variables which can be explored in examining the robustness of theoretical predictions. We feel that our design can be viewed to some extent as a "boundary" experiment for investigating the notion of rent dissipation in CPR environments. That is, from a parametric point of view groups are not extremely large (N - 8) and subjects are given explicit information on the marginal effects of investment in the CPR. If the behavioral results we obtain are contrary to predictions of rent dissipation then we would conclude that the environment necessary for theoretical confirmation might be obtained by altering one of our key experimental controls (eg. group size, openness of the resource, investment information, etc.). However, if our results tend to confirm the theoretical prediction of dissipation, they are suggestive of a theory that is quite robust. Further, one should note that our environment (parallel to Gordon's analysis) abstracts away from an environment in which investment decisions are time dependent. The complexity of this added dimension did not seem appropriate for a study designed to serve as a baseline for extending the investigation of resource appropriation in CPR environments. The complexity of intertemporal choice would have been confounded with our goal to investigate the behavioral hypothesis that individuals will ignore marginal production externalites and fully dissipate all rents.

IV. EXPERIMENTAL RESULTS: OUR INITIAL 18 EXPERIMENTS

A. Some Descriptive Observations

We begin our discussion with several descriptive comments which summarize our results. In Table 2, the mean, standard deviation, and range for percentage of maximum rents accrued is presented for all experiments. Summary measurements are also given aggregating across payoff conditions and subject experience. Several observations are illustrative of the general tendencies we found in our baseline experiments. First, looking across our two payoff conditions the average percentage of rents accrued differs very little. Ignoring the effect of subject experience, there is only a 1.3% difference between the mean of 35.2% for the high pay condition and 36.5% for the low pay condition.

Second, experience in the decision environment appears to lower the level of rents accrued on average. There is some evidence that this effect is strongest in the high pay condition. Viewed as a behavioral result that cooperation decreases with experience, this result is consistent with results reported by Isaac, Walker, and Thomas (1984)

TABLE 2

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

High Pay Design: All Experiments: 35.2, 26.4, -49 - 100

Inexperienced		Experienced	
1ihp:	48.1, 32.7, -21 - 100	1xhp:	22.6, 15.5, -14 - 58
2ihp:	35.7, 29.9, -21 - 100	2xhp:	24.1, 22.6, -14 - 65
3ihp:	46.7, 21.5, - 2 - 81	3xhp:	23.9, 24.0, -49 - 61
4ihp:	42.6, 29.8, -21 - 93	4xhp:	40.5, 20.6, -14 - 83
Pooled:	43.3, 28.6, -21 - 100	Pooled:	29.0, 19.6, -49 - 83

Low Pay Design: All Experiments: 36.5, 28.3, -49 - 100

Inxperienced		Experienced	
1ilp:	29.6, 39.7, -35 - 100	1xlp:	23.3, 22.4, -14 - 75
2ilp:	46.6, 20.8, 16 - 78	2xlp:	32.7, 18.6, -2 - 66
3ilp:	39.1, 29.8, -21 - 95	3xlp:	53.4, 26.3, 10 - 84
4ilp:	51.0, 27.8, 4 - 90	4xlp:	21.2, 22.4, -21 - 66
5ilp:	34.1, 27.5, -49 - 78		
6ilp:	37.6, 28.0, -28 - 78		
Pooled:	39.7, 29.7, -49 - 100	Pooled:	32.1, 30.2, -21 - 84

* All decision periods are used in calculating the descriptive statistics. Experiments ranged in length from 20 - 25 periods.

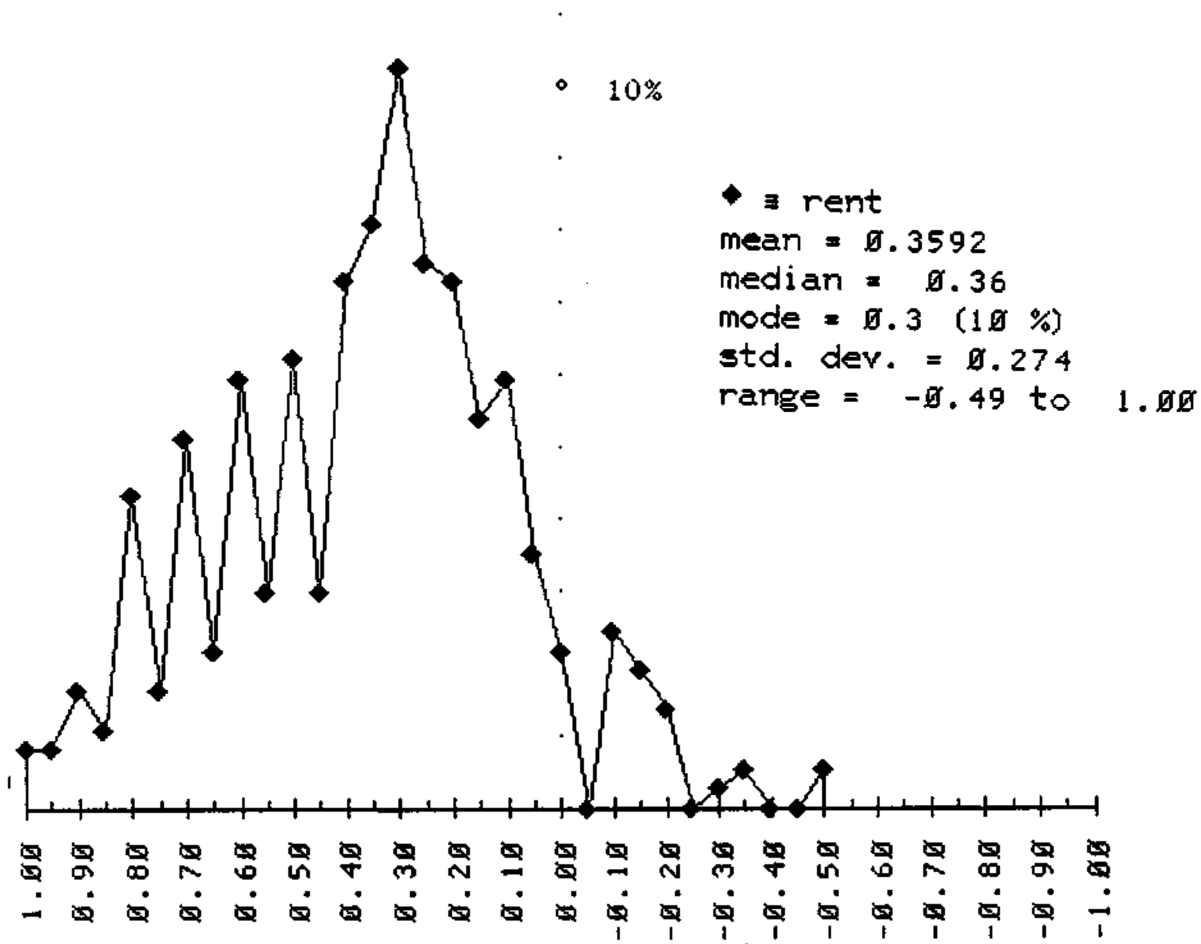
and Isaac and Walker (1988). In these studies greater levels of free riding were found in public goods experiments with experienced subjects than with subjects having no prior experience in the decision environment.

Third, the percentage of rents accrued ranges from a low of -49% to 100% of maximum. Note that the ability to earn negative rents occurs when decision makers as a group invest beyond the point of ARP-MC (consistent with zero rents) and actually earn a negative average return on their market 2 investments. This result, not discussed as a theoretical prediction, occurs due to the coordination problem inherent in this decision environment. In any given decision period, decision makers do not know a priori the level of investment chosen by others. It is this lack of information that leads to the observed result of negative rents. However, as illustrated in the frequency polygon shown in Figure 3, the accrual of rents is not symmetric around zero. In fact, in only 33 of 371 decision periods are rents negative.

Fourth, across all baseline experiments, we observe an average rent accrual of 36% of maximum. Ignoring the variance in rents across periods, this aggregate result lends the greatest support to the Nash equilibria predictions. Recall that for both payoff conditions all Nash equilibrium predict a market 2 investment of 59 tokens or approximately 41% of maximum rents. A simple t-test, using the mean percentage from each experiment as the unit of observation, confirms that we cannot reject (marginally) the null hypothesis of a population mean of 41% (t=1.90, d.f.-17, a=.05, two tail test). Although the mean of 36% does

FIGURE 3

RELATIVE FREQUENCY POLYGON:
DISTRIBUTION OF RENTS AS A PERCENTAGE OF MAXIMUM



not accurately parallel the theoretical prediction of zero rents, it is far from group optimality (100% rents).

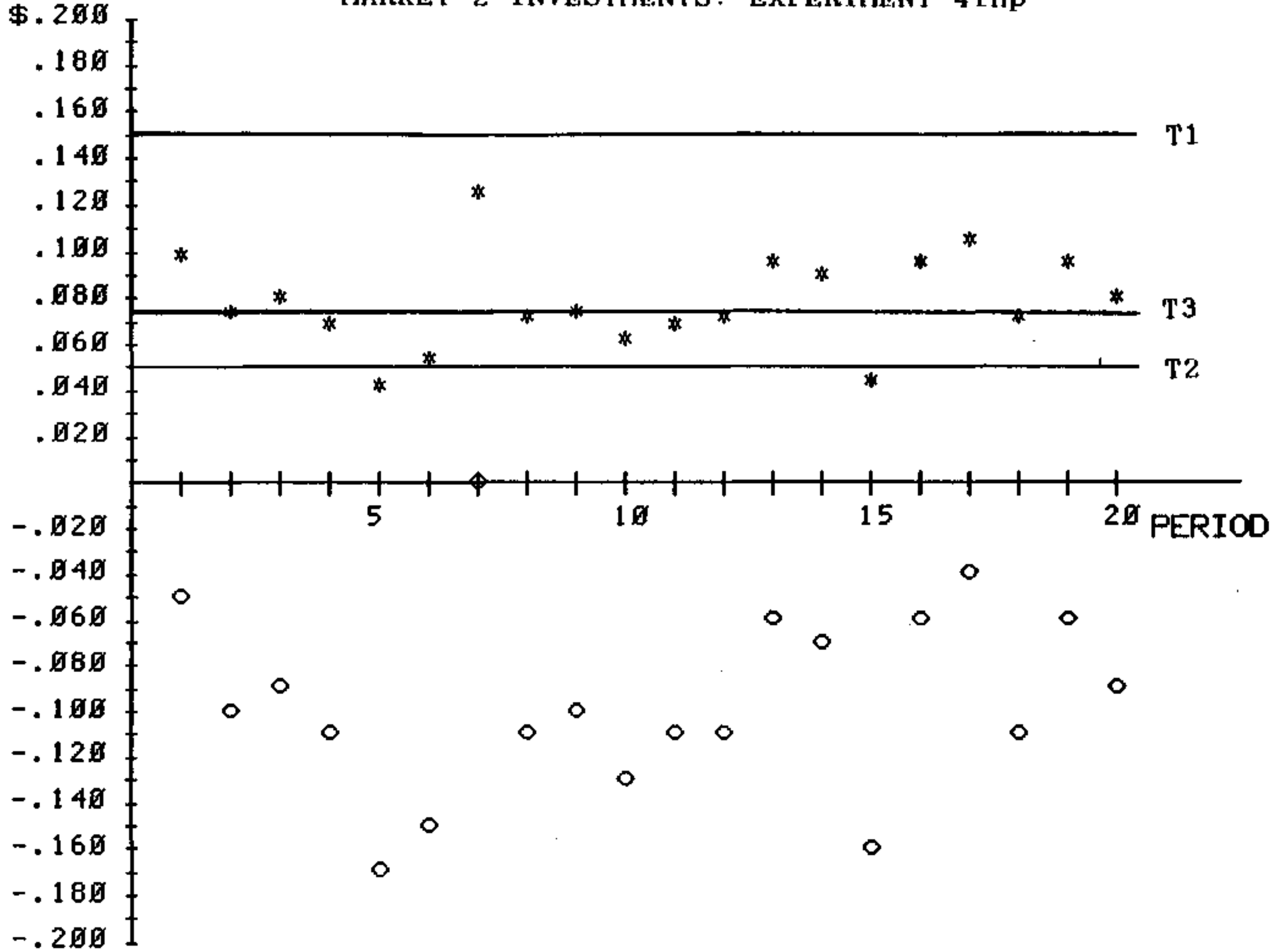
There is more going on behaviorally, however, than can be deduced from the aggregate descriptive statistics. In Figures 4a and 4b we present data on the period by period level of contributions for two representative experiments (4a = inexperienced high pay and 4b - experienced high pay). The standard rent dissipation theory predicts that market 2 investments will increase until the ARP=MC in market 2. In these figures we see a pattern which (to varying degrees) we found to be robust across all experiments. Investments in market 2 shows a "pulsing" pattern in which ARP is reduced to very close to MC at which time investors tend to drop out of market 2 and rents increase. This pattern tends to repeat itself throughout the experiment. We are not implying that we found symmetry across experiments in the magnitude of "rent peaks" or the timing of peaks. The general cyclical pattern is consistent, however, throughout our baseline experiments and in no experiment did we find a pattern in which rents remained anywhere close to maximum. For example, the maximum rent on average for any single experiment was 53.4%. For illustration, the results of this experiment are displayed in Figure 5. Finally, in no experiment did we find a general tendency for rents to increase as the experiment progressed.

B. A Formal Test of Experimental Treatments

This section presents the results of a classical linear model designed to more thoroughly test for shifts in behavior related to 1)

FIGURE 4a

MARKET 2 INVESTMENTS: EXPERIMENT 4ihp



Legend: * - observed ARP
o - observed MRP
T1 - ARP at maximum rents
T2 - ARP at zero rents
T3 - ARP at Nash equilibrium

FIGURE 4b

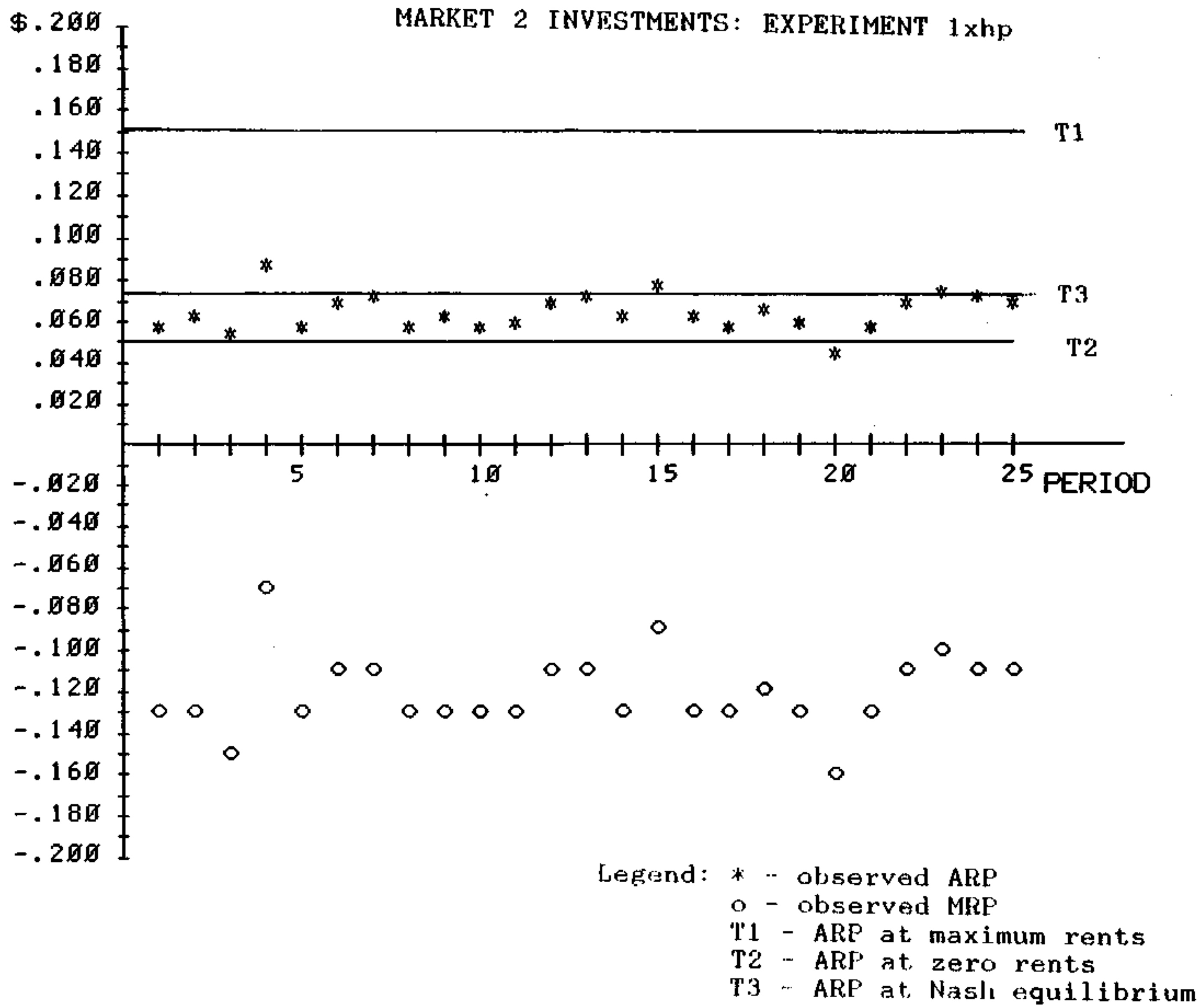
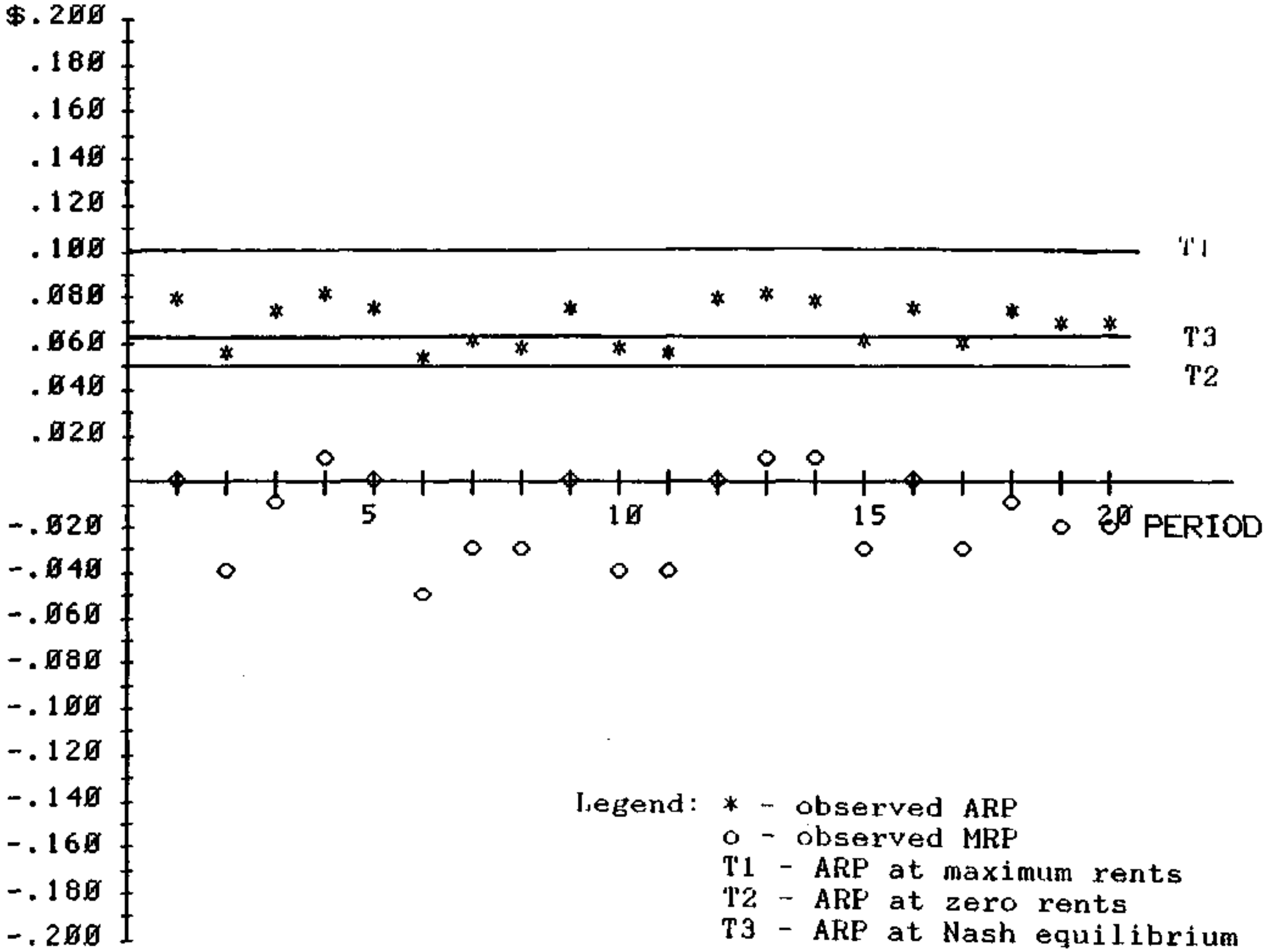

MARKET 2 INVESTMENTS: EXPERIMENT 1xhp
$.200
.180
.160
.140
.120
.100
.080
.060
.040
.020
-.020
-.040
-.060
-.080
-.100
-.120
-.140
-.160
-.180
-.200
5
10
15
20
25
PERIOD
T1
T3
T2
Legend: * - observed ARP
o - observed MRP
T1 - ARP at maximum rents
T2 - ARP at zero rents
T3 - ARP at Nash equilibrium

FIGURE 5

MARKET 2 INVESTMENTS: EXPERIMENT 3x1p



payoff condition, 2) subject experience, and 3) trends across an experimental sequence of decision periods. Specifically we test the model:

$$R_{ij} = B_0 + B_1 (PC) + B_3 (SE) + B_4 (SEQ2) + B_5 (SEQ3) + B_6 (SEQ4) + e_{ij}$$

where;

R = percentage of rents accrued in period i of experiment j.
PC = 1 if low pay condition and 0 otherwise;
SE = 1 if experienced and 0 otherwise;
SEQ2 = 1 if decision period is 6 - 10 and 0 otherwise;
SEQ3 = 1 if decision period is 11 - 15 and 0 otherwise;
SEQ4 = 1 if decision period is 16 - 20 and 0 otherwise;
e_{ij} = a random error term.

The results of our analysis are presented in Table 3. For consistency across experiments, this analysis uses only the first 20 periods in each experiment.

Consistent with our conclusions above, we find no significant impact from changing the payoff condition. Likewise, experience is found to have a statistically significant negative impact on the level of rents accrued. Somewhat arbitrarily, we separated the 20 periods into quartiles to investigate for a trend effect across experiments. The results confirm our suspicions that rents tend to decrease on average as the experiment progresses. Further, that decrease is most dramatic after the first several periods. (Note that the coefficients on all sequencing variables are negative. The difference in size of the impact, however, across the last three quartiles is small in comparison to their difference relative to the first quartile.) An analysis which uses decision period as the trend variable also shows a statistically significant negative relationship between periods and level of rents

TABLE 3

RESULTS FROM THE LINEAR MODEL

MODEL: $R_{ij} = B_0 + B_1 (PC) + B_3 (SE) + B_4 (SEQ2) + B_5 (SEQ3) + B_6 (SEQ4) + e_{ij}$

Variable	Coefficient	Std. Error	t-statistic	p-value*
Intercept	0.496	0.035	14.002	0.000
PC	0.004	0.029	0.155	0.851
SE	-0.111	0.029	-3.881	0.000
SEQ2	-0.102	0.040	-2.546	0.011
SEQ3	-0.108	0.040	-2.698	0.007
SEQ4	-0.139	0.040	-3.487	0.000

N = 360 Adjusted $R^2 = 0.063$ F-statistic (5,354) = 5.817 (p=.000)

* The p-value represents the lowest α value at which the null hypothesis of no difference from zero would be rejected in a two tail test.

accrued. This result implies that as the experiment progresses the strength of the zero rent prediction increases. However, in no experiment did we find stability at the zero rent outcome.

C. Individual Behavior - A Comparison with Predicted Nash Behavior

Until now, we have focused on aggregate levels of market behavior. In this section we take a closer look at individual behavior. Our results are organized around the Nash equilibria predictions for this decision environment. Recall that this symmetric game actually has 57 Nash equilibria. 56 of these are asymmetric and in pure strategies, with $\Sigma x_i = 59$. These are generated by having 5 players play $x_i = 7$ and 3 players play $x_i = 8$. The game also has a symmetric Nash equilibrium in mixed strategies, with $E(\Sigma x_i) = 59$ and $Var(\Sigma x_i) = 1.7$. This equilibrium is generated by each player playing $x_i = 7$ with probability .62 and $x_i = 8$ with probability .38.

In Table 4 we present frequency counts across experiments which describe the extent to which individual decisions match those predicted by the possible Nash equilibria. Specifically, the data in table 4 are classified with regard to two principal research questions.

Q1 - To what extent do period by period observations meet the criteria of 59 tokens allocated to market 2?

a) the number of periods in which 59 tokens were allocated in market 2.
b) if 59 tokens contributed to market 2, tne number of periods in which all subjects invested 7 or 8.
c) if 59 tokens contributed to market 2, the number of periods in which there were 5 equal to 7 and 3 equal to 8.

Q2 - What is the frequency of periods in which investments of 7 or 8 were made?

a) periods in which all investments were 7 or 8.
b) periods in which all but 1 investment was 7 or 8.
c) periods in which all but 2 investments were 7 or 8.
d) periods in which all but 3 investments were 7 or 8.
e) periods in which all but 4 investments were 7 or 8.
f) periods in which all but 5 investments were 7 or 8.
g) periods in which all but 6 investments were 7 or 8.
h) periods in which all but 7 investments were 7 or 8.
i) periods in which no investments of 7 or 8 were made.

The data in table 4 are aggregated within experience and payoff conditions, as well as over all experiments. The results are quite revealing. Unlike the results reported earlier on average rents accrued, the data on individual investments lend little support to the Nash prediction. With regard to question one (Ql), we found only 24 of 331 periods in which actual market 2 investments equaled the Nash prediction of 59. Further, there were no periods in which 59 tokens were invested and all investments were 7 or 8. The frequency counts related to Question 2 (Q2) illustrate the degree to which the individual decisions are missing the Nash prediction. These results are also not supportive of the Nash predictions. One can see from table 4 (columns Q2e through Q2g) that in 298 of 331 periods at least 4 players do not play the Nash strategy of investing 7 or 8 tokens into market 2. Although the results are not reported, we investigated questions Ql and Q2 for each individual experiment. No individual experiment stands out from the others. That is, even at the individual experiment level, we found no single experiment which systematically came close to matching the individual investment decisions predicted by the Nash equilibrium.

TABLE 4

PERIODS IN WHICH INDIVIDUAL INVESTMENTS WERE CONSISTENT WITH NASH

Experimental Condition*	Q1 a	Q1 b	Q1 c	Q2 a	Q2 b	Q2 c	Q2 d	Q2 e	Q2 f	Q2 g	Q2 h	Q2 i	Number of Periods
HPNX	9	0	0	0	0	1	8	6	21	25	16	3	80
HPX	5	0	0	0	0	2	5	20	20	15	4	0	66
LPNX	7	0	0	0	1	2	3	15	26	27	21	5	100
LPX	3	0	0	0	1	1	9	25	31	11	2	5	85
Aggregate	24	0	0	0	2	6	25	66	98	78	43	13	331

* The two experiments which used only 7 subject are deleted from this tabulation.

An alternative approach for investigating individual behavior is to focus on across period behavior for an individual. Did individuals consistently make the same investment choices? Did the pattern of choices vary across payoff conditions or experience? Was there evidence of learning (strategies consistently different in later periods compared to earlier periods of an experiment)? In table 5 we present frequency counts which can be used to shed light on individual choice patterns. The data are broken down into subjects whose market 2 investments always equal: 1) 9 or 10; 8 or 7; 6 or 5; 4 or 3; 2 or less and 2) 10 to 6 or 5 to 0. The latter division was chosen to investigate the frequency with which subjects consistently play a "non-cooperative" strategy (6 to 10) or a "cooperative" strategy (5 to 0). Panel A displays data using all periods of a given experiment, Panel B uses only periods 1-5 of a given experiment, and Panel C uses only periods 16-20 of a given experiment. Several observations can be drawn from the data. First, there is very little evidence of subjects playing strategies strictly defined to the two token intervals we chose. Of 144 subjects only 7 always fall into one of the two token intervals. Second, looking at Panel A, of those subjects always playing "cooperative" or always playing "non-cooperative" strategies, it is always the non-cooperative strategy that is played. Of 144 subjects, 41 always play a non-cooperative strategy. Third, Panels B and C suggest that there is some "learning" of strategies over the experiments using inexperienced subjects. In experiments with inexperienced subjects the number of players playing non-cooperative strategies in periods 16-20 almost doubles compared to periods 1-5. In experiments with experienced

TABLE 5

INDIVIDUAL DATA: CONSISTENCY IN INVESTMENT PATTERNS

PANEL A - ALL PERIODS

Experimental Condition	Number of Individuals Investing 9,10	8,7	6,5	4,3	2,1,0	10 - 6	5 - 0
HPNX	0	0	0	0	0	6	0
HPX	2	0	0	0	0	13	0
LPNX	2	0	0	0	0	7	0
LPX	2	1	0	0	0	15	0

PANEL B - PERIODS 1-5

Experimental Condition	Number of Individuals Investing 9,10	8,7	6,5	4,3	2,1,0	10 - 6	5 - 0
HPNX	2	1	1	0	0	11	2
HPX	2	1	0	0	0	19	0
LPNX	2	0	0	0	0	11	1
LPX	4	1	1	0	0	21	0

PANEL C - Periods 16 - 20

Experimental Condition	Number of Individuals Investing 9,10	8,7	6,5	4,3	2,1,0	10 - 6	5 - 0
HPNX	3	2	3	0	0	19	0
HPX	2	2	0	0	0	17	1
LPNX	10	2	1	0	0	23	1
LPX	4	4	3	0	0	23	1

subjects there is little change in the frequency in periods 16-20 compared to 1-5.

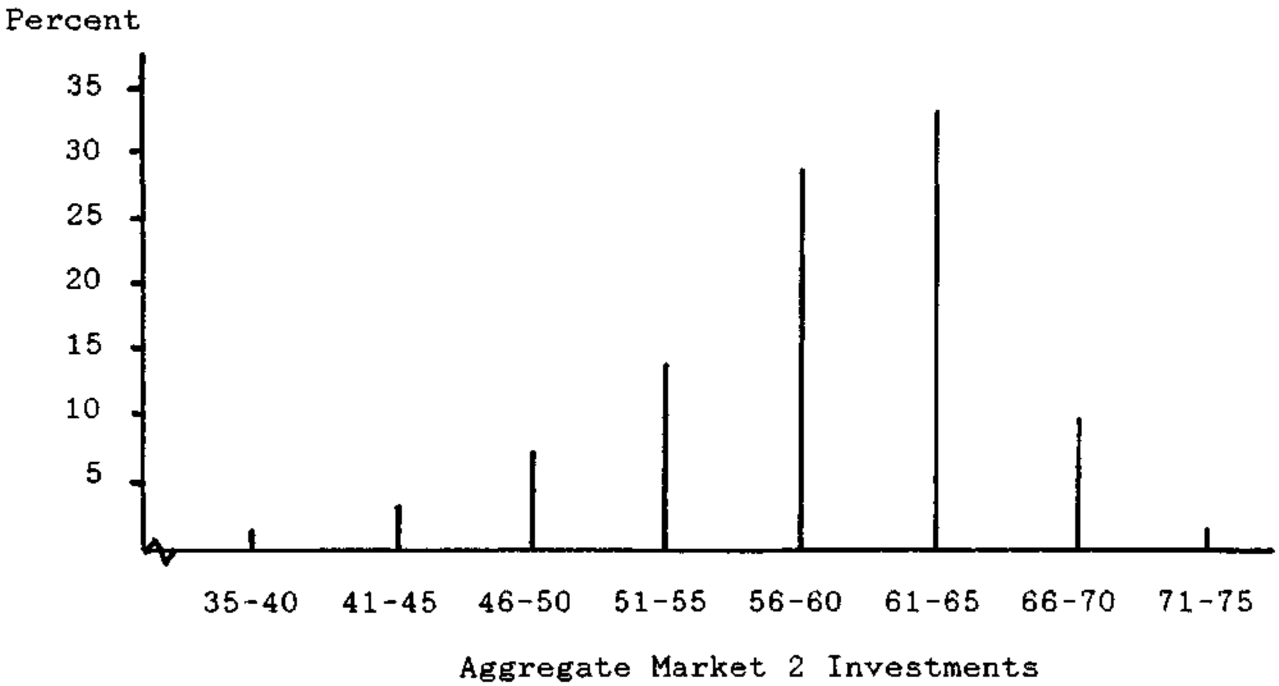
As a final summary on individual and group contributions, we present in Figure 6 a relative frequency histogram describing the distribution of individual and group decisions aggregated across all experiments. The distributions reflect several important trends across experiments. The data on aggregate investments in market 2 reinforce the results reported for rent accrual. Sixty two percent of the group investments fall in the range of 56-65 tokens, a range encompassing the Nash prediction of 59 and falling quite close to the zero rent prediction of 66.

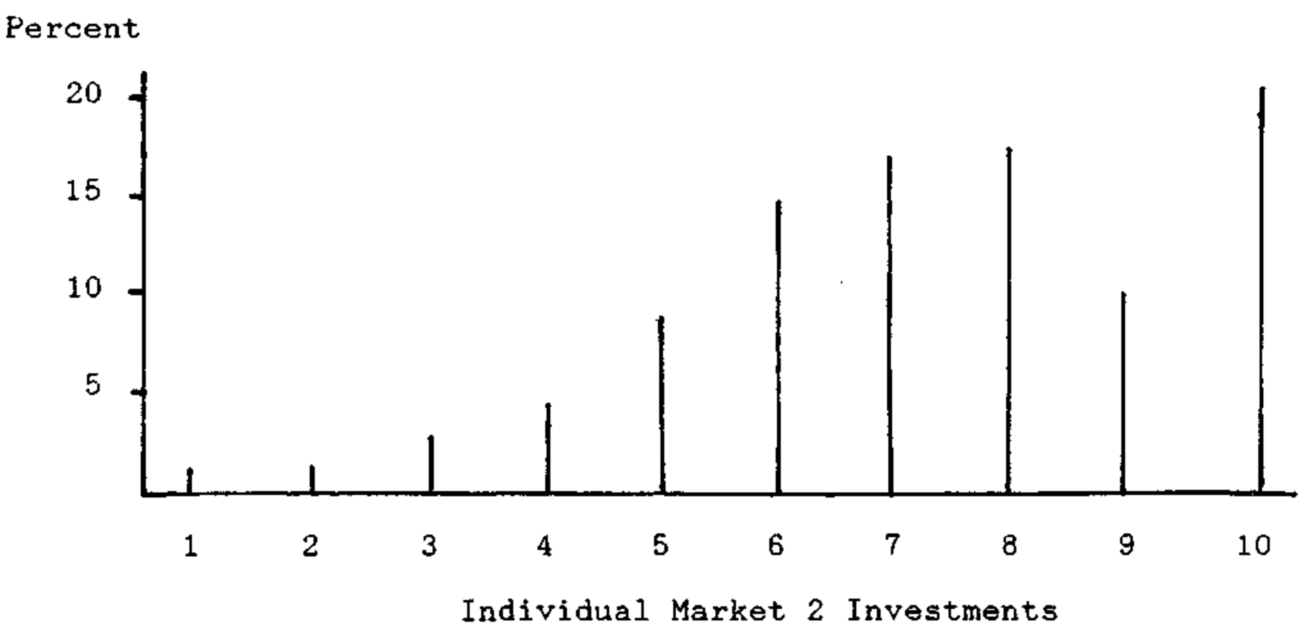
More revealing, however, is the data on individual contributions. First, rent maximization requires individual investments of 4 tokens each (for the symmetric case). Only, 4.4% of the individual investments equalled 4. Further, only 16.6% of the individual investments are equal to five or less. It is worth noting that several of our experiments had groups obtaining very close to optimum rents in the first few periods of the experiment. In no case, however, was the group able to stabilize at this result. Further, in most of these cases the optimum was reached with considerable variation in individual investment as opposed to symmetric investments in the neighborhood of 4 tokens each.

Second, the individual data from Figure 6 provides information related to why groups were unable to reach the Nash equilibria prediction of individual token investments of 7 or 8. The modal individual investment is 10 tokens. That is, across experiments, there

FIGURE 6

FREQUENCY HISTOGRAMS
AGGREGATE AND INDIVIDUAL MARKET 2 INVESTMENTS





was a strong likelihood of finding at least one subject frequently investing all 10 tokens in market 2. Further, it was not unusual to see a pattern in which the number of subjects investing all 10 tokens in market 2 increased as the experiment progressed.

V. EXPERIMENTAL RESULTS: EXPERIMENTS WITH ZERO MARGINAL COSTS

Although our experiments do not show a stable pattern of complete rent dissipation, they do show a systematic pattern of severe suboptimality and a cyclical pattern of decay toward full rent dissipation. As a check on the robustness of this result, we conducted a second set of "boundary" experiments in which the return from investing tokens in market 1 equalled zero. Thus, if groups followed a pattern of decay toward zero rents, they would earn no cash returns in each decision period since average return per token would equal the marginal cost of zero. If behavior in this design repeats the behavior observed in our initial design, it sheds further light on the strength of the rent dissipation argument.

We conducted these experiments utilizing the design parameters of our high pay experiments with two changes: 1) subjects were endowed with 15 tokens each, and 2) prior to the first decision period subjects received an endowment of $5.00. With the high payoff condition, ARP=0 at a group investment of 83 tokens. For this reason, we increased token endowments so that full rent dissipation would not be a corner solution. Further, with this design it is possible for subjects to actually have negative returns for a decision period. For this reason, and to leave subjects with some minimal experimental earnings, we added the up front cash endowment. Our subjects for these experiments were all experienced.

In table 6 we summarize the results from our three "zero marginal cost" experiments. There does appear to be a small impact of reducing the value of market 1 investments to zero when compared to the data from table 2 for high pay/experienced experiments. As shown in table 6, the average (pooling across all experiments) for rents accrued is 40.6%. This compares to an average of 29% for the parallel high pay/experienced experiments. If we treat each experiment as a single observation, however, the difference in means is not statistically significant (t=1.713, d.f.=5).

Further, we see from Figure 7 that the market 2 investment pattern for these three experiments is strikingly similar to those of our initial set of experiments. The cyclical pattern of decay to zero or near zero rents is systematic across all three experiments. However, one can see (especially in experiment 2-x-hp-zmc) some tendency for the decay to be inhibited by the boundary condition that investments which lead to zero or negative rents also lead to zero or negative payoffs for the decision period.

VI. SUMMARY AND CONCLUDING COMMENTS

A generally accepted premise in the literature focusing on resources held in common is that resource users, working independently, will over exploit the resource in question leading to rent dissipation

TABLE 6

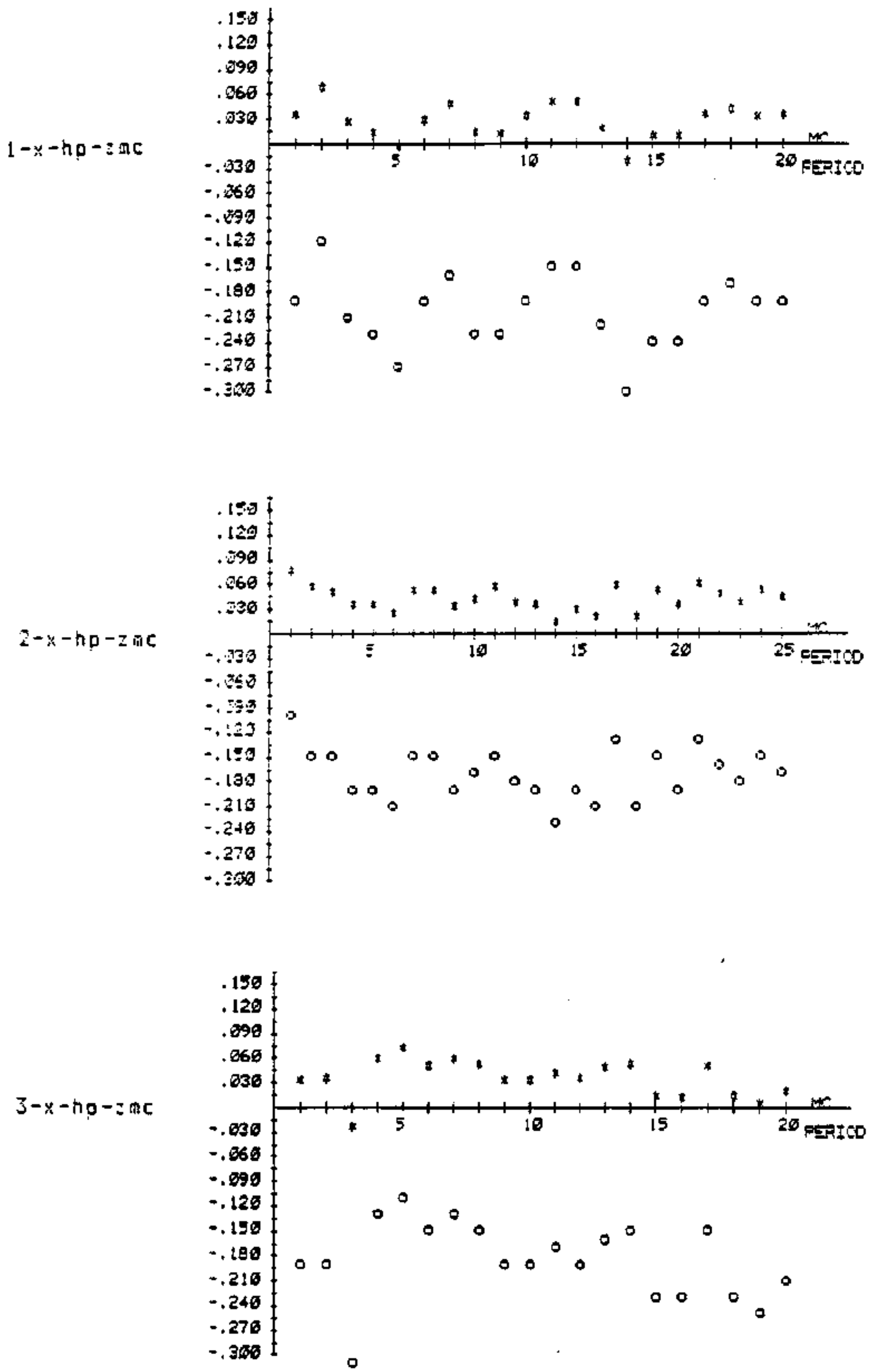
DESCRIPTIVE STATISTICS: ZERO MARGINAL COST EXPERIMENTS

PERCENTAGE OF RENTS ACCRUED
(mean - standard deviation - range)

	Mean	Standard deviation	Range
1-x-hp-zmc:	29.8	28.57	-46 - 76
2-x-hp-zmc:	50.5	16.74	15 - 83
3-x-hp-zmc:	39.5	30.47	-52 - 78
pooled:	40.8	26.42	-52 - 83

FIGURE 7

MARKET 2 INVESTMENTS: ZERO MARGINAL COST EXPERIMENTS
(* = ARP - o = MRP)



and possible resource destruction. The field research focusing on this question is abundant with case studies of suboptimal exploitation in many environments and what appears to be efficient resource usage in others. Using experimental methods to control for subject incentives and increase the degree to which inefficient production can be measured, this study investigates the degree to which suboptimal appropriation occurs in an environment designed to parallel that of an open access common pool resource.

We interpret our experimental design as a "boundary" experiment for investigating the notion of rent dissipation in CPR environments. Groups were not extremely large (N = 8) and subjects were given explicit information on the marginal effects of investment in the CPR. To the extent that our behavioral results are contrary to predictions of rent dissipation, one is left with controllable experimental variables whose levels can be varied to search for theoretical confirmation (eg. group size, openness of the resource, investment information, etc.). However, to the extent that our results confirm the theoretical prediction of dissipation, they are suggestive of a theory that is quite robust.

In summary, our results strongly support a research hypothesis of suboptimal appropriation. Across all experimental conditions, subjects earn on average only 37% of possible rents. Further, the level of rent dissipation tends to increase when subjects are experienced in the decision environment and with repetition of the decision process. Contrary to the predictions of zero rents, however, we do not find our experimental markets stabilizing at a level of rents approximately equal to full dissipation. Instead, we observe a general pattern across experiments where rents decay toward zero then rebound as subjects exit the common pool investment.

We feel that our completed research offers a tightly controlled bench mark against which future research can be compared. Our plans are to extend this work with research directed in three primary areas. First, is the cyclical pattern of rents that we observe robust over extended parameter spaces? Specifically, do rents tend to stabilize toward zero (or do cycles exhibit smaller peaks) as payoff conditions are varied and/or group sizes increase. Second, what is the impact of allowing subjects the opportunity to communicate. Our research in this area will begin with environments in which subjects can communicate freely. After obtaining these, baseline communication results we can extend the research to areas such as a) communication with heterogeneous resource users; and b) communication rights which are costly to obtain. Finally, we plan to extend our experimental environments into a time dependent decision framework where current period decisions affect the profitability of choices in future periods. As this work proceeds, we can compare the generalizabilty of our experimental findings to those from parallel field research which is currently underway.

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FOOTNOTES

1. Following Gardner, Ostrom and Walker (1988) we define a CPR to be a natural or man made resource system from which a flow of subtractable (rival in consumption) resources are available over time and: i) are sufficiently large that it is costly (but not necessarily impossible) to exclude potential beneficiaries from appropriating resource units, or ii) in which properties rights are such that potential appropriators cannot be legally excluded.

2. Following Plott and Meyer (1975), we distinguish between the process of withdrawing resource-units from the resource (appropriation) and the actual resource system itself. As discussed in Gardner, Ostrom and Walker (1988), the CPR dilemma may actually be composed of numerous "separable" allocation problems. The work here focuses on one subset of these choice problems, efficient "appropriation". While the resource system may be jointly used the actual resource-units are not subject to joint use. In appropriation problems, the allocation problem to be solved focuses on how to allocate the yield from the CPR in an economic and equitable fashion. For analytical purposes, appropriation questions can be separated from "provision" questions which relate to creating the resource, maintaining or improving the production capabilities of the resource, or avoiding the destruction of the resource.

3. Rents accrued as a percentage of maximum - (Return from market 2 minus the opportunity costs of tokens invested in market 2)/(Return from market 2 at MR-MC minus the opportunity costs of tokens invested in market 2). Opportunity costs equal the potential return that could have been earned by investing the tokens in market 1.