THE COMMONS:

AN EXPERIMENTAL EXAMINATION

OF

INDIVIDUAL BEHAVIOR

Dean Dudley

Indiana University 1989

Prepared for presentation at the mini-conference for the Workshop in Political Theory & Policy Analysis. April 29 and May 1, 1989.

I. INTRODUCTION

A large and rich body of literature has evolved around the concept of the social dilemma. In particular, social dilemma literature has focused on the problem of individual incentive incompatibilities. This problem arises when the incentives of a free and competitive market induce rational individuals to make choices that lead to socially sub-optimal outcomes. An environment which commonly induces incentive incompatibilities is the one in which individuals have open access to a common pool ~~property~~ resource (cpr). Ocean fisheries are considered a prime example of such an environment. The incentive structure of an open access cpr leads individuals to over invest their productive capacities in mining the resource. This results in the inefficient dissipation of economic rents.

Lets distinguish between the resource — the common pool resource — and the property arrangement.

There are two behavioral models which can be applied to this type of social dilemma. The first is the model of rent dissipation introduced by H. Scott Gordon (1954). It is assumed in this model, that additional effort exerted in mining the resource has a negative external impact on the productivity of the effort already applied to mining the resource. Individuals making decisions, as to the amount of effort to expend in mining the resource, will ignore the external effects of their decisions and concentrate on the average return of their effort. They will therefore exert ~~mining~~ withdrawal effort to the point where the average return from their effort is equal to the marginal opportunity cost associated with that effort. Activity of this nature results in the total dissipation of economic rents.

The second approach to modeling this social dilemma also assumes that additional effort has a negative external impact on the effort already exerted, but it does not assume that this external impact is totally ignored. Individuals are assumed to evaluate the impact of their exertion of another unit of effort on the productivity of the effort they are already exerting, given an expectation as to the effort levels of the other individuals. Thus, individuals will exert effort to the point where their marginal return from effort is equated to the marginal opportunity cost of exerting that effort.

$$MRP_{ie} = MC_{ie}$$

This implies there may be a Nash equilibrium solution to the exerting of effort.

Both of these approaches to the cpr problem suggest that individuals will ignore a portion or all of the external costs associated with exerting an additional unit of effort. This implies that individuals will exert effort to the point where the marginal revenue product of such effort is less than its marginal opportunity cost.

$$MRP_{e} < MC_{e}$$

In the special cases where individuals are endowed with a single unit of effort and are faced with the binary decision, exert that unit of effort or not exert it, or where they are endowed with multiple units of effort but there are no external effects of their additional exertion on their own previous effort, the Nash model will predict the same individual behavior and thus the same aggregate outcome as the rent dissipation model. That is, the average revenue product of effort will equal the marginal opportunity cost of that effort.

$$MRP_{\bullet} < ARP_{\bullet} = MC_{\bullet}$$

In a truly competitive framework, where the individual agents are atomistic and an individual's exertion of effort would have no impact on the aggregate level of effort, the predictions of the Nash model would converge to those of the rent dissipation model. In an experimental setting, where the number of agents is limited, there will be a separation between the predictions of the Nash and rent dissipation models. This separation will be exploited in the experimental analysis.

This paper will replicate the symmetric Nash design experiments described in Walker, Ostrom and Gardner (1989). In that paper, the authors found that the experimental environment induced the dissipation of a significant portion of the available economic rents. But, the subjects never stabilized at the zero rents prediction forwarded by Gordon (1954). A second observation was that, in the aggregate, rents were dissipated to the point predicted by the Nash equilibrium solution. Though there was this result, the individual decision pattern predicted by the Nash equilibrium was not achieved.

There are two questions which are not addressed by the

Walker, Ostrom and Gardner (1989) paper which will be addressed in this paper. Though Nash equilibrium was not attained in the experiments of Walker et al, the data was not examined to see if individuals were on their reaction functions. One or two subjects acting with non-Nash behavior would prevent the group from achieving the predicted equilibrium, even if the others engaged in Nash strategies. Thus, even if the Nash equilibrium can be rejected, can the weaker proposition of individual Nash strategizing be supported? The second question is related to how well the Walker et al environment approximated an open access environment. Was rent dissipation limited by the parameterization of the experiment?

Due to the computer hardware constraint faced by experimenters, it is not possible to increase the subject group size substantially. Thus, the open access environment in Gordon's (1954) paper can only be approximated. One way of approximating the open access nature is to increase the token endowment. Does increasing each individual's endowment lead to a closer approximation of Gordon's predicted outcome?

Section II of this paper will describe the experimental environment used to test the research questions. Section III will develop the research questions from their underlying theoretical foundations. Section IV will summarize the experimental results and tests, and section V will convey the summary and conclusions.

II. THE EXPERIMENTAL ENVIRONMENT

A. The Subjects

The subjects in all of the experiments were drawn from introductory microeconomics classes at Indiana University. Before potential subjects were asked to volunteer they were told that they would be expected to make decisions in a simulated economic environment. They were also told that the money they made during the experiments would be dependent upon their own decisions as well as the decisions of the others participating in the experiment. The volunteers which were chosen, were all trained in the decision environment with a 20 period run of the baseline experimental design. A total of 24 subjects were trained. All data reported was generated from subjects who were experienced in the decision environment.

The experiments were computerized and run on the PLATO computer terminal cluster at Indiana University. All of the terminals were separated by blinders, allowing for a maximum amount of privacy to the subjects. The use of a computerized environment enhances the uniformity of conditions faced by subjects from experimental run to experimental run. It also minimizes the interaction between the experimenter and the subjects, thus minimizing the transference of experimenter's biases.

B. The Experimental Design

After the subjects were checked in and assigned PLATO terminals, but before they were allowed to proceed into the experiment, they were told verbally, by the experimenter, the importance of reading and understanding the ensuing computerized instructions. In addition, they were told that payments would be made in cash and in private at the conclusion of the experiment; and that once they had started reading the instructions, they should make no noises or communications. If they had any questions, the subjects were told they should be addressed to the experimenter.

The computerized instructions explained the specifics of the particular decision environment in which the subjects would be working.

The experiment was a multi-period game, where each individual was endowed each period with a number of tokens (Y^{io}). The individual had to invest these tokens between two experimental markets. Market 1 was a market which yielded a constant rate of return on every token invested. Market 2, the cpr, yielded a rate of return dependent upon the aggregate investment level in market 2. Each individual received an individual return in proportion to his investment in market 2.

The subjects had access to a limited amount of information. This information consisted of the explicit functional form of the market 2 production function, as well as a table of values which summarized the production function. At the end of each period the subjects were given a listing their personal earnings for that period, broken down to show their total returns from each market, as well as the total investment level in market 2. Their personal investment history was accessible through out the experiment.

The two designs of this experiment are distinguished by the endowment level. In the first design the individuals were endowed with 10 tokens. In the second design the individuals were endowed with 25 tokens. In each design the subjects knew how many participants were in the experiment. In the second design, before the start of the experiment, all individuals were explicitly informed that they would be paid at one half of their experimental earnings. This was to equalize the potential per period payoffs at the Nash equilibrium. To minimize the effects of possible collusive behavior outside of the experimental environment no group was reassembled, in its entirety, in a second experiment, nor were they told in how many experiments they would participate.

III. PREDICTIONS

As outlined in the introduction there are two theoretical frameworks which can be used to predict the outcomes of the experiments previously described. Those two frameworks are the rent dissipation model and the Nash model. This section will take those two models and combine them with the explicit parameterizations used in the experiments to yield testable predictions.

A. The Nash Model

The Nash equilibrium is a concept which assumes that individual agents act in such a way as to maximize their individual profits contingent upon the activities of all involved. An equilibrium is attained when each agent's expectations of the actions of the group as a whole are consistent with the actual actions of the group.

In the case of the experiments there were eight agents, each of whom were endowed with either ten or twenty five tokens (depending upon the particular experimental design). These tokens were generic productive inputs for two different production processes (market 1 and market 2). The productive process in market 1 was such that each token invested was transformed into an output valued at five PLATO cents.[1] The output of the productive process in market 2 was contingent upon the aggregate level of tokens invested in market 2, and the individual agents production of market 2 output was strictly proportional to his investment of tokens into the production process. Each output from market 2 was valued at one PLATO cent.

An individual's revenue R(*) was the simple sum of his

---

[1] In the first design, where the agents were endowed with 10 tokens each period, there was a one to one exchange rate between PLATO dollars and U.S. dollars. In the second design, where individuals were endowed with 25 tokens each period, there was an exchange rate of one half to one between PLATO dollars and U.S. dollars. This was to equate per-period earnings between the two designs at the Nash equilibrium.

production of market 1 and market 2 outputs multiplied by their respective prices P_i.

$$R^i = P_1[Y_{1i}] + \frac{P_2 Y_{2i}}{\Sigma Y_{2j}}[a\Sigma Y_{2j} - b(\Sigma Y_{2j})^2]$$

Where: $j = \{1,2,...,8\}$
Y_{ki} - Is agent i's investment of tokens in market k.

Since the agents were endowed with these generic production units, and since there was no cost associated with investing the tokens, each agents costs of production were zero (C(*) = 0). This leaves profits π(*), the difference between revenues and costs, equal to revenues R(*). Yielding:

$$\pi(Y_i) = 5[Y^o - Y_i] + \frac{Y_i}{\Sigma Y_j}[a(\Sigma Y_j) - b(\Sigma Y_j)^2]$$

Where: Y^o - Is the agents endowment of tokens.
Y_i - Is agent i's investment in market 2.
$(Y^o - Y_i) = Y_{1i}$.
$P_1 = 5$ and $P_2 = 1$.

If agents acted as if they were Nash type agents, they would strive to maximize their profit function subject to their expectations of the aggregate investment in market 2. Thus, their investment strategy in market 2 must satisfy the following necessary first order condition where:

$$\frac{d(\pi(Y_i))}{dY_i} = a - 5 - 2bY_i - b\Sigma Y_j = 0$$

Where: $j = \{1,2,...,8\}$ and $j \neq i$, or everyone except agent i's investment in market 2.

[The second order conditions for maximization are satisfied due to the specific quadratic form of the market 2 production function.]

Solving for Y_i yields the reaction function for agent i:

$$Y_i = \frac{(a - 5)}{2b} - \frac{1}{2}E(\Sigma Y_j).$$

Where E(*) is the individuals expectation relation.

Inserting the parameter values used in the experiments for the market 2 production function, of a = 23, and b = .25, the reaction function becomes:

$$Y_i = \begin{cases} Y_i, & \text{if } 0 \leq 36 - .5E(\Sigma Y_j) \leq Y^o \\ 0, & \text{if } 0 > 36 - .5E(\Sigma Y_j) \\ Y^o, & \text{if } Y^o > 36 - .5E(\Sigma Y_j) \end{cases}$$

Thus, Y_i will maximize individual i's profits when his expectation of the aggregate market 2 investment is consistent with the actual market 2 investment. A Nash equilibrium can be achieved only when all agents' expectations of group investment levels are consistent with actual levels. If all agents' expectations are consistent and they are investing according to their reaction functions, they would be maximizing their profits and would have no incentive to move from that point. It is this incentive which generates the equilibrium.

Since the individual agents in the experiment are facing the same revenue and cost structures, they will have the same reaction functions. This will yield a system of eight equations.

Solving for the equilibrium condition[2] results in:

$$Y_i = 36 - 3.5(Y_i)$$

or, $$Y_i = 8, \quad \text{for } i = \{1,2,...,8\}$$

Simply stated, there is a symmetric Nash equilibrium where all agents are investing eight tokens in market 2.

The Nash equilibrium concept yields three propositions:

1) The aggregate investment level in market 2 will be 64 tokens per period.

2) Each individual will invest 8 tokens when equilibrium is attained.

3) Individuals will invest on their reaction functions.

The first two propositions were examined with some detail in Walker et al (1989). The third proposition is not necessarily an equilibrium condition. It is only a behavioral aspect reveled by agents who use the Nash strategy.

B. Rent Dissipation

The rent dissipation model predicts that agents will invest in market 2 to the point where the average return to tokens invested in market 2 is equal to the marginal opportunity cost of investing those tokens. The opportunity cost of investing tokens

---

[2]This equilibrium solution is independent of the token endowment only as long as the endowment of each individual is not such that the agent's choice set does not include the symmetric solution. If the solution were to predict an investment of 12 tokens when agents were endowed with only 10 tokens, the solution would not be in the agents choice set.

in market 2 is the return those same tokens would generate in market 1. In both designs of the experiment, market 1 returned a constant 5 PLATO cents per token invested. This yields a marginal return in market 1 of 5 cents for every token, or a marginal cost of investing in market 2 of 5 cents.

The return in market 2 is conditional on the aggregate investment level in market 2.

$$r = a\Sigma Y_i - b(\Sigma Y_i)^2$$

Which yield an average return of:

$$ARP_2 = \frac{r}{\Sigma Y_i} = \frac{a\Sigma Y_i - b(\Sigma Y_i)^2}{\Sigma Y_i}$$

or,

$$ARP_2 = a - b\Sigma Y_i$$

Inserting the experimental values of a = 23 and b = .25, and solving for ARP_2 = MC yields:

$$23 - .25\Sigma Y_i = 5$$

or,

$$\Sigma Y_i = 72.$$

The rent dissipation model predicts an aggregate market 2 investment level of 72 tokens. This prediction is independent of the aggregate endowment of tokens, as long as it exceeds 72. In the first experimental design, where the individual's endowment is 10 tokens, achieving the rent dissipation model's prediction requires an aggregate investment of 90% of the total available tokens in market 2. Because of the small group size and the large investment requirement, one individual's investment strategy could adversely effect the rent dissipation model's predictions. This violates the open access concept. To address this issue the second experimental design with a 25 token endowment was run. In the second design rent dissipation occurs with an aggregate investment level equal to only 33% of the total available tokens. Thus, no one individual controls enough tokens to prevent market 2's rents from being dissipated.

IV. EXPERIMENTAL RESULTS

A. The Aggregate Investments

The first question addressed by the aggregate investment patterns of the six experiments is that of rent dissipation. The model predicts an aggregate investment level of 72 tokens. As presented in table 1, in the three design 1 experiments, where individuals were endowed with 10 tokens each, a simple two tailed means test rejects that aggregate investment is as predicted by theory in all three runs. These tests were conducted at an alpha level of .05, with the critical t = 2.042.

The concern is, though, that the design 1 experiment does not approximate the open access environment required by the rent dissipation theory. The design 2 experiments, where individuals were endowed with 25 tokens each, were designed to overcome that concern. In all three runs of design 2, the means test failed to reject that the aggregate investment levels were significantly different from that predicted by rent dissipation theory. Again the alpha level was .05, but the critical t = 2.086. The difference in t-statistics is due to the difference in the number of periods in the two designs.

The pooled design 2 data also failed to reject that the aggregate investment level was significantly different from that predicted by the rent dissipation model.

TABLE 1

Experiment	Y	$Y - Y_N$	$Y - Y_{RD}$
10tk;01	67.333	5.333 (7.345)	-4.667 (-6.428)
10tk;02	61.767	-0.233 (-0.370)	-10.233 (-16.241)
10tk;03	63.633	1.633 (1.965)	-8.367 (-10.067)
25tk;01	66.400	6.400 (2.351)	-3.600 (-1.322)
25tk;02	73.000	11.000 (2.986)	1.000 (0.271)
25tk;03	68.300	6.300 (3.080)	-3.700 (-1.809)
pooled 10tk	64.422	2.422 (5.092)	-7.578 (-15.933)
pooled 25tk	69.767	7.767 (4.666)	-2.233 (-1.342)

The design 1 experiments show the same tendency commented on in Walker et al (1989), that is, the aggregate investment levels are not significantly different from the Nash equilibrium prediction. This is evident in the second and third runs of design 1. It is this phenomenon which spurred the first look into the individual agents investment strategies.

B. Individual Behavior

With a close inspection of the individual investment strategies of design 1 subjects, even though their aggregate investment was as predicted by Nash equilibrium, in no period did their individual investment strategies equal that predicted by Nash equilibrium. In none of the ninety periods, the three 30 period runs of design 1, did all individuals invest 8 tokens.

This does not repudiate that individuals act to maximize profits subject to expectations of group investment. It only indicates that the individual expectations do not become consistent with one another.

In order to investigate whether individuals invest on their reaction functions, estimations as to how individual expectations are formed are needed. In this paper two expectation schemes are used and their results compared. The first is to assume individuals are able to forecast perfectly the current periods investment level. Though this not a reasonable assumption it is a useful extreme. In fact, individuals may have complex expectation frame works which closely approximate perfect foresight. The second expectation scheme is an adaptive format, where individuals assume the current periods investment will be the same as that of the last period.

Under these two expectation schemes, the two reaction functions faced by individual subjects become:

$$Y_{it} = \begin{cases} Y_{it}, & \text{if } 0 \leq 36 - .5(\Sigma Y_{jt}) \leq Y^{o} \\ 0, & \text{if } 0 > 36 - .5(\Sigma Y_{jt}) \\ Y^{o}, & \text{if } Y^{o} > 36 - .5(\Sigma Y_{jt}) \end{cases}$$

and,

$$Y_{it} = \begin{cases} Y_{it}, & \text{if } 0 \leq 36 - .5(\Sigma Y_{j(t-1)}) \leq Y^{o} \\ 0, & \text{if } 0 > 36 - .5(\Sigma Y_{j(t-1)}) \\ Y^{o}, & \text{if } Y^{o} > 36 - .5(\Sigma Y_{j(t-1)}). \end{cases}$$

From these definitions of the reaction functions it is possible to predict the per-period investment strategies of the individual subjects. Table 2 shows that in the design 1 experiments subjects are investing within 1 token of their reaction function predictions between 30% and 47% of the time. In the design 2 experiments the subjects are not as close to their reaction function predictions. This is fairly intuitive considering the design 2 experiments induced more rent dissipating behavior.

Table 2

	EXPERIMENT NO.					
	10tk;1	10tk;2	10tk;3	25tk;1	25tk;2	25tk;3
$-1 < Y-Y_r < 1$	72	105	109	15	12	30
(%)	30%	44%	45%	9%	8%	19%
$-1 < Y-Y_{r(t-1)} < 1$	79	108	103	18	18	26
(%)	34%	47%	44%	13%	13%	17%

Y is individual investment level.
Y_r is the current period reaction function prediction.
$Y_{r(t-1)}$ is the lagged one period reaction function prediction.

These results indicate there is a tendency for individuals to invest near the levels predicted by their reaction functions, but they do not indicate whether individuals are consistently investing at their reaction function levels. A simple means test was employed to compare each individual's investment strategy against the two reaction functions. For 16 of the 24 subjects in design 1 experiments, the test rejected they were using either of the Nash strategies. This contrasts with the surprising result that the test only rejected Nash strategizing for 11 of the 24 design 2 subjects.

Table 3

Experiment	Subject	$Y - Y_r$	t	$Y - Y_{r(t-1)}$	t
10tk;1	1**	0.200	0.443	0.190	0.570
	2	1.767	4.175	2.017	5.868
	3**	0.983	1.822	1.121	2.069
	4	2.383	5.478	2.603	7.270
	5	2.133	4.951	2.138	5.436
	6	2.583	6.841	2.603	6.716
	7	1.933	4.729	1.897	4.944
	8	2.667	7.689	2.776	8.074
10tk;2	1	-1.150	-4.126	-1.103	-5.055
	2	-0.983	-2.546	-0.845	-2.483
	3**	-0.417	-1.449	-0.362	-1.099
	4	-2.250	-7.380	-2.276	-9.145
	5	-2.033	-6.996	-1.931	-6.859
	6	0.550	3.299	0.569	3.126
	7	-1.817	-5.565	-1.500	-4.264
	8**	-0.483	-1.508	-0.224	-0.799
10tk;3	1**	-0.333	-0.515	-0.207	-0.358
	2**	0.333	0.851	0.293	0.808
	3	-1.200	-2.621	-1.155	-2.312
	4	-1.067	-2.610	-1.293	-3.765
	5	1.533	5.205	1.293	4.890
	6	1.000	3.059	0.931	3.108
	7**	0.533	1.363	0.466	1.034
	8**	0.150	0.400	-0.034	-0.087

Table 3 cont.

Experiment	Subject	$Y - Y_r$	t	$Y - Y_{r(t-1)}$	t
25tk;1	1	6.200	4.324	5.711	4.214
	2*	4.725	3.395	3.526	2.007
	3**	1.750	1.622	0.842	0.783
	4*	4.050	2.969	3.658	2.041
	5*	-0.400	-0.348	-2.053	-2.496
	6	5.400	2.700	4.368	2.169
	7**	0.050	0.045	-0.658	-0.665
	8**	0.000	0.000	-0.816	-0.706
25tk;2	1	7.175	4.935	7.553	5.179
	2	7.575	3.203	7.579	3.511
	3**	-0.125	-0.073	-0.289	-0.266
	4	3.600	2.151	3.474	2.248
	5**	-0.750	-0.664	-0.632	-1.485
	6**	3.325	1.983	2.895	1.809
	7*	2.850	1.959	3.711	2.351
	8	5.300	3.698	5.737	5.645
25tk;3	1	4.450	4.042	4.158	4.532
	2	2.125	2.211	2.211	2.337
	3	4.275	5.079	4.579	4.904
	4**	1.600	1.719	1.500	1.820
	5**	-0.250	-0.166	-0.737	-0.494
	6**	1.075	0.924	1.053	1.260
	7	4.250	3.009	4.447	2.488
	8**	0.125	0.167	0.237	0.324

* not significantly different from one reaction function
** not significantly different from both reaction functions

In both designs, Nash strategizing behavior can only be rejected in 54% of the cases. In the 46% of the cases where Nash strategizing is descriptive of individual behavior, both reaction functions were descriptive 82% of the time. This may indicate that a perfect foresight model is a fairly descriptive approximation of the individual's expectations function.

V. CONCLUDING REMARKS AND COMMENTS

The experimental evidence shows that increasing the token endowment from 10 to 25 tokens increased the rent dissipating behavior of the experimental groups. This may be because the 10 token endowment adversely affected the experimental design's ability to approximate an open access environment. The rent dissipation model predict a consistent group investment of 72 tokens in market 2. This consistency is never achieved. The group investment falls erratically around the predicted level.

This erratic behavior leads to questions about the individual strategies which may have caused the unstable aggregate investment. In investigating the individual strategies, Nash type behavior was observed on the part of some individuals. Just under half of the subjects showed signs of Nash strategizing.

The tests were far from conclusive and they were ambiguous as to which of the two models best describe the cpr environment. Support was found for both. This could be because agents act in both manners. They make profit maximizing decisions as long as they see the benefits from the effort exceeding the costs of forecasting. When their subjective forecasting costs exceed potential benefits the individuals revert to the less complex task of using the ARP as an approximation to their individual MRP. This would lead them to full rent dissipation. Only a few individuals would have to revert to dissipate all economic rents, if their endowment is large enough. Individuals moving between the two strategies would cause the erratic nature of the group investment levels.

REFERENCES

F. Bell, "Technological Externalities and Common Property Resources: An Empirical Study of the U.S. Lobster Industry", Journal of Political Economy, Vol. 80 No. 1, Pg. 148-158 (1972).

R. Gardner, E. Ostrom, and J. Walker, "The Nature of Common Pool Resource Problems", Bloomington IN: Indiana University, Workshop in Political Theory and Policy Analysis, working paper (1989).

S. Gorgon, "The Economic Theory of a Common Property Resource: The Fishery", Journal of Political Economy, Pg. 124-142, (1954).

H. Varian, Microeconomic Analysis 2nd edition, Pub. W. W. Norton & Company, 1984.

J. Walker, E. Ostrom, and R. Gardner, "Rent Dissipation in Open Access Common Pool Resource Environments: Experimental Evidence", Bloomington IN: Indiana University, Workshop in Political Theory and Policy Analysis, working paper, (1989).