ESSAYS ON INDIVIDUAL BEHAVIOR IN SOCIAL DILEMMA ENVIRONMENTS: AN EXPERIMENTAL ANALYSIS

Dean Dudley

Submitted to the faculty of the Graduate School
in partial fulfillment of the requirements
for the degree
Doctor of Philosophy
in the Department of Economics
Indiana University

November 1993

Accepted by the Graduate Faculty, Indiana University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Doctoral Committee:

James M. Walker, Chair

Roy J Gardner

Steven C. Hackett

Elinor Ostrom

Arlington W. Williams

Date of Oral Examination:

June 2, 1993

Acknowledgements

In the course of my study at Indiana University, I have received support from many individuals. Without a doubt, my greatest debt is to Sarah Lou Dudley. Her kindness, guidance and loving support made all of my accomplishments possible. Along with Sarah, I need to add my appreciation for Stephanie, David, Whitney, Jarod and James.

In addition, I owe a great debt of gratitude to James Walker. His encouragement, and insightful responses to initial drafts led to the timely completion of this work. He is an ensign of professionalism, scholarship, and personal integrity worthy of emulation.

I have been enriched greatly by conversations with and course work from Roy Gardner, Steve Hackett, Elinor and Vincent Ostrom, and Arlington Williams. They have served as reservoirs of moral, technical, and intellectual support. I would, also, like to thank fellow students with whom invaluable discussions took place. In particular, I want to thank Steve Lewarne, Frank Raymond, Phil Sprunger, Clement Wong, and Jim Zilliak.

The financial and technical support of the Department of Economics and the Workshop in Political Theory and Policy Analysis must be greatfully acknowledged. In particular, the research associate position offered by "the Workshop" when most of this dissertation was written. Research funding from National Science Foundation grants SES-8820897 and SES-8921884 is, also, greatfully acknowledged.

Finally I would like to thank friends who kept me grounded in the real world while I was a student. In particular I want to thank Raymond and Jeannie Butler, Brett and Carolyn Sweeney, Bishop and Ruth Teh, and Lloyd and Martha Taysom.

Essays on Individual Behavior in Social Dilemma Environments: An Experimental Analysis

There is an extensive literature covering decision environments where agents engaging in private benefit maximizing (privately rational) behavior generate Pareto inferior outcomes in comparison to agents engaging in social welfare maximizing (socially rational) behavior. Predictive models in these social dilemma environments rely on assumptions as to whether agents are privately rational or socially rational. Casual empiricism can lend support to either assumption of agent rationality. We see societies, groups of individuals, subjecting themselves to laws, to norms and to traditions even in instances where the individual could achieve higher short-run payoffs by deviating. We also see contaminated water, over used resources, and crime caused by agents sacrificing long-run social good for short run private gain.

In this study, individual level behavior is investigated in the context of computer assisted voluntary contribution mechanism public good (VCM) provision experiments and common pool resource (CPR) appropriation experiments. Previous studies of these environments have concentrated on aggregate outcomes and have found, on average, aggregate outcomes fall between the predictions of the models based on privately rational agents and socially rational agents.

In the VCM provision experiments, 43% of the subjects behave consistently with a predictive model based on private rationality (Nash) and 21% of the subjects behave consistently with a predictive model based on social rationality. In the CPR appropriation experiments, 74% of the subjects behave consistently with a predictive model based on private rationality and 5% of the subjects behave consistently with a model based on social rationality. Both of these results help to explain why the aggregate outcomes fall between the privately and socially rational model predictions. The third essay investigates subject forecasting behavior in the CPR provision environment. Here, subjects tend to efficiently use scarce information revealed through lagged forecast error, but their forecasts are biased. This result is not consistent with rational expectations forecasts. Subject forecast behavior is better described by a Bayesian point estimate updating model with an updating weight approaching one on prior beliefs. This outcome is consistent with the observed failure of subjects to converge to an equilibrium outcome, in the CPR experiments.

Doctoral Committee

Professor James Walker, Chair

Professor Roy Gardner

Professor Steve Hackett

Professor Elinor Ostrom

Professor Arlington Williams

Table of Contents

List of Tables

Chapter 4

List of Figures

CHAPTER 1

INDIVIDUAL BEHAVIOR IN SOCIAL DILEMMAS: AN INTRODUCTION

The extensive literature on social dilemmas focuses on the divergence between outcomes generated by individuals engaging in private benefit maximizing (privately rational) behavior and the outcomes generated by individuals engaging in social welfare maximizing (socially rational) behavior (Dawes [1980]). This divergence of outcomes occurs when there is an incompatibility between the private incentives faced by the individual and the incentives consistent with generating the maximum total welfare of the society (Messick and McClelland [1983]). In short, the problem addressed in this literature is the failure of atomistic and self-interested behavior to achieve socially optimal outcomes.

Individuals who face a social dilemma environment must choose strategies for interaction. Theories based on strict private rationality predict that the individuals will choose to maximize their short-run personal welfare. These types of strategies will lead to socially suboptimal outcomes in social dilemma environments. Theories based on strict social rationality in human interaction predict that individuals will choose strategies which maximize social welfare.

Casual empiricism lends support to both of these theories of human interaction. We see societies, groups of individuals, subjecting themselves to laws, to norms and to traditions even in instances when the individual could achieve higher payoffs, in the short run, by deviating from this course of action. We also see contaminated air and water, over exploited resources, and crime caused by individuals sacrificing the long-run social good for short- run private gain.

An example of a social dilemma is a common-pool resource (CPR). A

CPR is characterized by a commonly held stock that is exploited by a set of appropriators. The most frequently discussed examples of CPRs include irrigation systems, ocean fisheries and commonly held grazing and forest lands. Agents associated with a CPR face two general problems. The first is a provision problem and the second is an appropriation problem (Gardner, Ostrom and Walker [1990]) .

The provision problem comes in two forms, both of which stem from the same underlying economic environment. The first is the supply side provision of or maintenance of the resource itself. In the irrigation example this would be the provision and upkeep of the dams and the distribution canals. This provision problem emanates from the providers ability to shirk, relying on some other provider making the provision effort. Thus, this environment generates the free-riding problem of public goods provision. The second provision problem is the demand side provision of resource capability made through individual agents when they decide when and how they will use the resource (Gardner, Ostrom and Walker [1990]). This problem is evident in fisheries where next year's harvest is dependent on the breeding population left behind after the current harvest.

The appropriation problem associated with the CPR environment is derived from a production externality in scale. That is, the inputs an individual appropriator employs to exploit the CPR has adverse effects on the productivity of all the rest of the inputs employed to exploit the CPR. Thus, individual appropriators do not face the full marginal impact of their appropriation decisions. The appropriation problem can be analytically separated from the provision problem whenever the appropriators treat the resource (the stock) as given.

This study consists of three essays in which a series of computer assisted experimental environments are used to collect the individual choices made by providers and appropriators in social dilemmas. These observed choices are then compared to the choices predicted by behavioral models with one of the two underlying hypotheses of human interaction (private rationality and social rationality). The first essay examines the supply-side CPR provision problem in the context of a repeated play voluntary contribution public goods environment. In this environment, the provider has private incentives to "free-ride" resulting in socially sub-optimal private resource contributions toward the provision of the public good (Samuelson [1954] and [1955]). Observed experimental behavior confirms that, in aggregate, individuals under-contribute from a socially rational perspective and over-contribute from a privately rational perspective (Isaac, Walker and Thomas [1984]). This essay concentrates on individual level behavior in the repeated play environment, which has not been systematically studied to this point.

The second essay examines the classic production externality CPR appropriation problem in a limited-access environment. In this environment the appropriator has private incentives to over contribute private resources toward exploiting the CPR and partially dissipates the available economic rents (Clark [1980]). Experimental studies of this CPR appropriation environment support Clark's rent dissipation prediction (Walker, Gardner and Ostrom [1990]), but do not find convergence to the predicted Nash equilibrium. Again, the studies concentrate on aggregate level and not individual level behavior. The second essay investigates individual level appropriator behavior.

Since the strategies predicted by both private rationality and social welfare maximization are contingent on the individual's beliefs of cohort behavior, an individual's behavior reflects both his underlying rationality and his beliefs. Thus, deviations from purely Nash equilibrium play (private rationality) or purely social rational play can be due strategy choices inconsistent with private or social rationality, or due to poorly formed beliefs. Collection of individual forecast data gives information on subject beliefs, poorly formed or not, and allows a direct comparison of that individual's behavior to the theoretic behavioral predictions from the two paradigms of rationality.

The third essay examines the subjects' forecasts of cohort behavior. Forecast formation hypotheses such as the rational expectations hypothesis and adaptive learning make assumptions about the character and structure of subject's forecasts. These characteristics can be tested for through experiments. The third essay finds little support for Muthian rational expectations forecasts in the CPR and Public good experiments; the adaptive model is more descriptive of subjects' forecasts. In addition, there is evidence of non-zero bias in the forecast errors. This bias can account for some of the outcomes observed in the CPR and public good experiments.

Over all, the three essays examine individual level forecasting and choice behavior to find why experimental evidence fails to support the solutions predicted by private and social rationality.

CHAPTER 2

INDIVIDUAL PROVISION CHOICES IN VOLUNTARY CONTRIBUTION PUBLIC GOODS ENVIRONMENTS: AN EXPERIMENTAL APPROACH

I. Introduction

A large body of the social dilemma literature focuses on the "free-rider" or "cheap-rider" problem associated with the voluntary provision of public goods. In this environment, short-run private benefit maximizing (privately rational) agents have incentives to under-reveal their demand for the public good, resulting in socially sub-optimal private resource contributions toward the provision of public goods (Samuelson [1955]).

Many of the previous experimental investigations of this phenomenon concentrate on environments where the socially optimal resource contribution is 100% of a subject's resource endowment and the privately rational resource contribution is 0% of a subject's resource endowment, as in Isaac and Walker (1988). Observed experimental behavior in this type of environment confirms that, on average, individuals under-contribute from a social welfare perspective but over-contribute from a privately rational perspective (Isaac, Walker, Williams [1993]).

This study considers voluntary contribution public good provision environments where the privately rational contribution level is an interior solution. That is, the joint contribution level of privately rational agents is strictly positive and less than the group's total endowment. Given this environment, this study investigates how individuals allocate their private resources when given a choice between investing those resources toward the provision of a public good or toward the provision of a private good. Using data from a series of computerized public goods experiments, observed allocation paths are compared to the theoretic paths predicted under the assumption of privately rational providers and the assumption of social welfare maximizing providers[1]. From this comparison, an underlying model of subject behavior is evaluated.

The next section of this paper outlines the public goods provision problem. Sections III and IV outline the general experimental environment and the specific parameterizations used. Section V presents the results, and concluding comments are presented in section VI.

II. The Public Good Provision Problem

To address the resource allocation problem associated with public goods provision, the following formal framework of the voluntary contribution decision environment is used. An individual making the decision to contribute resources toward the provision of a public good must take into account the following factors.

1) There are N potential providers.
2) Each potential provider is endowed with Y° units of a resource which can be allocated toward the provision of the public good.
3) Each provider can allocate Y_i e $[0, Y^\circ]$ = I units of the resource toward the provision of the public good, leaving $(Y^\circ - Y_L)$ units of the resource to allocate toward the provision of a private good.
4) The private good has a constant marginal return of C.
5) Y^T allocated toward the provision of the public good yields a benefit to each individual of Q_i where
   A) $Q_i = [1/N]\ g(Y^T)$, and where
   B) $Y^T = \sum_{j=1}^{N} Y_j$ is the aggregate resource allocation toward the provision of the CPR.

---

[1]These experiments consist of 13 non-forecasting experiments run by Isaac and Walker (1992), supplemented with 6 new forecasting experiments.

C) $g(Y^T)$ is the social benefit from a public good provided by Y^T units of resource.

D) $g(Y^T)$ exhibits diminishing marginal benefits.

The Social Welfare Maximizing Provider. Within the provision framework, the social welfare maximizing provider faces a social benefit function of:

$$\sum_{i=1}^{N} \pi(Y_i \; Y^T) = \sum_{i=1}^{N} Q_i + C(NY^\circ - Y^T)$$
$$= g(Y^T) + C(NY^\circ - Y^T) . \qquad (2.1)$$

Thus, this provider, seeking to maximize social benefit faces the resource allocation problem of:

$$\max_{Y_i} g(Y^T) + C(NY^\circ - Y^T) . \qquad (2.1a)$$

This yields the first order condition of:

$$\frac{dg(Y^T)}{dY^T}\frac{dY^T}{dY_i} = C\frac{dY^T}{dY_i} \quad \text{or,} \quad \frac{dg(Y^T)}{dY^T} = C \qquad (2.2)$$

since, $\frac{dY^T}{dY_i} = 1.$

since, $\frac{dY^T}{dY_i} = 1.$

The social welfare maximizing provider allocates resources toward public good provision to the point where the marginal social benefit of the resource is equated to its marginal cost.

The Privately Rational Provider. A privately rational provider faces a private benefit function of:

$$\pi(Y_i \backslash Y^T) = Q_i + C(Y^\circ - Y_i \qquad (2.3)$$
$$= [1/N] g(Y^T) + C(Y^\circ - Y_i) .$$

The resource allocation problem is:

$$\max_{Y_i} [1/N] g(Y^T) + C(Y^\circ - Y_i) . \qquad (2.3a)$$

Yielding,

$$\frac{1}{N}\frac{dg(Y^T)}{dY^T}\frac{dY^T}{dY_i} = C \quad \text{or,} \quad \frac{1}{N}\frac{dg(Y^T)}{dY^T} = C \qquad (2.4)$$

since, $\frac{dY^T}{dY_i} = 1.$

This implies the privately rational provider will allocate resources to the public good to the point where the social marginal benefit from the resources are equal to N times their marginal cost.

Since $g(Y^T)$ exhibits diminishing marginal benefits, the privately rational provider will under-invest in the provision of the public good.

The two paradigms of choice lead to two competing models of behavior type: for privately rational individuals the behavior described by equation (2.4) and for social welfare maximizers the behavior described by equation (2.2). Under specific parameter choices, these theoretic descriptions of agent behavior can be tested against observed experimental outcomes. The next section develops the basic experimental decision environment faced by the subjects.

III. The Experimental Setting

The experiments used student volunteers recruited from the undergraduate populations at Indiana University and the University of Arizona. Before subjects were recruited from their respective classes, the students were informed that, should they volunteer, they would be making economic choices in a computerized decision environment. They were also told that their earnings in this experimental environment would be contingent upon their choices and the choices of their cohorts. The subjects first participated in a trainer experiment to give them experience in the decision environment. This trainer experiment used the same decision environment as those used in this study, but had different parameterizations.

The trained subjects were assigned a NovaNET computer terminal and logged into the experiment. They then worked through a set of computerized instructions explaining their particular decision environment. A full transcript of the computerized instructions is in Appendix A. In a subset of these experiments, the subjects made one-period ahead forecasts of aggregate cohort investment choices. In these experiments, the subjects read a supplementary instruction sheet explaining the forecasting procedure after they finished the computerized instructions. A full transcript of the supplementary instructions is at the end of Appendix A. The experiment monitor reviewed the additional instructions orally to make certain the subjects understood the forecasting procedure. If the subjects had any questions about the instructions, or had questions during the experiment, these questions were directed to the experiment monitor. After the instructions, the subjects were told they would be paid their experimental earnings, in cash, in private, at the conclusion of the experiment. They were instructed to refrain from all forms of inter-subject communication and then they proceeded into the experiment.

Each experiment consisted of 4 subjects engaging in 10 repetitions of the voluntary contribution public goods game[2]. In each repetition the participants chose how much of their endowment (Y° = 62 tokens[3]) to invest in each of 2 exchanges. The first exchange was a private exchange that yielded a fixed return for each token invested. The second exchange was a group exchange. Each participant received 1/4 of that exchange's return. The return from the group exchange depended upon the total tokens invested by the group. The group exchange produced the public good.

The individual's payoff from the private exchange was:

$$\pi^p(Y_i) = C(Y^\circ - Y_i) ,$$

where C = 1 cent in all of the experiments. The individual's payoff from the group exchange was

$$\pi^g(Y^T) = \frac{1}{N}\left[aY^T - b(Y^T)^2\right], \text{ where } Y^T = \sum_{i=1}^{4} Y_i,$$

and where the ordered pair (a, b) = (4.96, 0.01) in one set of experiments and (a, b) = (8, 0.01) in another set of experiments. (The particulars of these two experimental treatments are summarized in Table

[2]The duration of the experiment and the symmetry of the endowment were given explicitly in the instructions and reaffirmed verbally by the experiment monitor prior to actual participation in the experiment.

[3]A token is a generic productive resource used in the two exchanges.

1.) This yields an individual's private payoff function of

$$i(Y_i\ Y^T) = i^p(Y_i) + i^g(Y^T) = C(62 - Y_i) + 1/N\,[aY^T - b(Y^T)^2]$$

and a social welfare function of

$$\Sigma_{i=1}\, i(Y_i\ Y^T) = C(248 - Y^T) + [aY^T - b(Y^T)^2].$$

At the end of each round, subjects received information on their individual earnings from each exchange and the aggregate investment level in the group exchange. Their personal earnings and personal investment history was available for examination throughout the experiment.

There were two experimental treatments. The first treatment was the parameter set for the group exchange payoff function. As shown in the next section, two parameter sets were chosen to yield two distinct symmetric Nash equilibria. These parameter sets resulted in a high Nash equilibrium (hereafter Nash-200) where the aggregate group exchange Nash investment level was 200 tokens and a low Nash equilibrium (hereafter Nash-48) where the aggregate group exchange Nash investment level was 48 tokens.

The Nash-200 and the Nash-48 parameters were chosen to match the Isaac and Walker (1992) experiments. The symmetry of the aggregate endowment space above the Nash-200 experiments and below the Nash-48 (and the converse symmetry) allowed them to investigate the hypothesis that contributions away from Nash equilibrium could be interpreted as error, and the direction of that error was a function of the aggregate strategy space around the Nash prediction. It allows for a similar investigation of a systematic subject type bias due to Nash equilibrium level.

The second treatment was forecasting. In a subset of each of the Nash-200 and Nash-48 experiments subjects made one-period ahead forecasts of aggregate cohort group exchange investment levels. At the end of these experiments, a period was randomly selected and the subject whose forecast was closest to his cohorts actual investment level was paid an additional $3.00. This payoff scheme was selected because it had no impact on the Nash nor the socially optimal incentive structure and therefore no impact on the Nash nor the socially optimal strategies. Yet, it gave an incentive for the subjects to forecast accurately.

The preceding section outlined the general environment faced by subjects. To make specific outcome predictions, the particular parameterizations of each experiment are examined.

IV. Theoretic Solutions

The two paradigms of human interaction, coupled with the specific functional forms in the experiments, yield two possible models of subject behavior. These are the Nash model for the privately rational and the social welfare maximizing model. This section develops predictions made by these models.

The Nash Model. When individuals act as Nash type agents, they must select Y_i to maximize their individual payoff function given their <u>beliefs</u> of the aggregate investment level in the group exchange $\hat{Y}^T$. Thus, an agent will choose Y_i to maximize

$$ii(Y_i\ Y^T) = 1/4[aY^T - b[Y^T]^2] + C(62 - Y_i) \qquad (4.1)$$

Yielding a first order condition of

$$\frac{di()}{dY_i} = a - 2b\hat{Y}^T - 4C = 0,$$

or

$$Y_i = \frac{a - 4}{2b} - \hat{Y}^T_{-i} \qquad (4.2)$$

where $C = 1$ and $\hat{Y}^T_{-i} = \hat{Y}^T - Y_i$.

Substituting in the parametric values for (a, b) yields the following

$$Y_i = 200 - \hat{Y}^T_{-i} \qquad (4.3)$$

for the Nash-200 experiments, and

$$Y_i = 48 - \hat{Y}^T_{-i} \qquad (4.4)$$

for the Nash-48 experiments. Given the individual agent's token constraint, equations (4.3) and (4.4) yield the following best response functions

$$Y_i^{BR} = \begin{cases} 0 & \text{for } Y_i < 0 \\ 48 - Y^T & \text{for } Y_i \in \{0, 1, \ldots, 62\} \\ 62 & \text{for } Y_i > 62 \end{cases} \qquad (4.5)$$

for the Nash-200 experiments and

$$Y_i^{BR} = \begin{cases} 0 & \text{for } Y_i < 0 \\ 48 - Y^T & \text{for } Y_i \in \{0, 1, \ldots, 62\} \\ 62 & \text{for } Y_i > 62 \end{cases} \qquad (4.6)$$

for the Nash-48 experiments.

Individual i maximizes private earnings by investing Y_i in the group exchange when his belief of his cohort's investment in the group exchange matches their actual investment. A Nash equilibrium is achieved when beliefs and actual cohort investment match for all the subjects.

Since all of the subjects face the same experimental incentives, there exists a symmetric Nash equilibrium where $Y^T_{-i} = (N-1)Y_i$ Yielding the symmetric Nash equilibrium group exchange investment of

$$Y_i = 200 - 3Y_i$$

or,

$$Y_i = 50, \quad \forall\, i \in \{1, 2, 3, 4\} \qquad (4.7)$$

for the Nash-200 experiments. And, for the Nash-48 experiments

$$Y_i = 48 - 3Y_i$$

or,

$$Y_i = 12, \quad \forall\, i \in \{1, 2, 3, 4\}. \qquad (4.8)$$

The symmetric equilibrium is not the only equilibrium in the Nash-200 nor the Nash-48 experiments. The agents' first order conditions are met when $Y^T = 200$ tokens in the Nash-200 and when $Y^T = 48$ tokens in the Nash-48 experiments. This condition is indifferent to the individual contribution levels as long as the aggregate investment level is 'correct'. Thus, there are a multitude of equally Pareto ranked Nash equilibria[4].

---

[4]It is possible to modify the group exchange production function to yield unique Nash equilibria. One possibility, would be to scale a subject's group exchange return to his group exchange investment. The problem with this process is that it relaxes the purely public nature of the group exchange and comparability to previous pure public good experiments would be diminished.

Social Welfare Optimization. A social welfare maximizing individual will choose Y_i to maximize the joint payoff function given his beliefs of cohort investment levels. Or,

$$\max_{Y_i} \Sigma_{i=1}^{4} \pi(Y_i, \hat{Y}^T) =$$
$$\max_{Y_i} (248 - \hat{Y}^T) + (a\hat{Y}^T - b(\hat{Y}^T)^2). \qquad (4.9)$$

This yields the first order condition of

$$\hat{Y}^T = \frac{a - 1}{2b}, \quad \text{or} \quad Y_i = \frac{a - 1}{2b} - \hat{Y}^T_{-i}. \qquad (4.10)$$

Substituting the parameters for the Nash-200 and Nash-48 experiments into equation (4.10) yields

$$Y_i = 350 - \hat{Y}^T_{-i} \qquad (4.11)$$

for the Nash-200 experiments and

$$Y_i = 198 - Y^T_{-i}, \qquad (4.12)$$

for the Nash-48 experiments.

Taking the subjects token endowments into consideration yields the following best-response functions.

$$Y_i^{BR} = \begin{cases} 0 & \text{for } Y_i < 0 \\ 350 - \hat{Y}^T_{-i} & \text{for } Y_i \in \{0, 1, ..., 62\} \\ 62 & \text{for } Y_i > 62 \end{cases} \qquad (4.13)$$

for the Nash-200 experiments and

$$Y_i^{BR} = \begin{cases} 0 & \text{for } Y_i < 0 \\ 198 - \hat{Y}^T_{-i} & \text{for } Y_i \in \{0, 1, ..., 62\} \\ 62 & \text{for } Y_i > 62 \end{cases} \qquad (4.14)$$

for the Nash-48 experiments.

Using the symmetry of the incentive structure, a symmetric solution emerges where

$$Y_i = 350 - Y^T_{-i} \quad \text{or} \quad Y_i = 350 - 3Y_i$$

yielding

$$Y^*_i = 62 \quad \forall i \in \{1, 2, 3, 4\}$$

for the Nash-200 experiments since subject's choices are constrained by their endowmenr of 62 tokens each[5]. For the Nash-48 experiments,

---

[5]This is a unique solution, so the supergame solution is the repeated play of this solution. This is independent of symmetry since 62 tokens is a corner, given the subject's endowment.

$Y_i = 198 - Y_{-i}^T$ or $Y_i = 198 - 3Y_i$

yielding

$Y_i = 49.5$ or the symmetric mixed strategy of $Y_i = \{49, 50\}$, where 49 and 50 are each played with a probability of P = 0.5. The symmetric mixed strategy solution is played since the subjects must make integer valued investments. Again, there are a multitude of equally Pareto ranked solutions. Only the symmetric solution will be considered.

Three Mixed Subject Type Solutions. There are also three solutions considered that involve mixed subject types. The first is when one subject is maximizing social welfare while the other three subjects are privately rational. The second is when two subjects are social welfare maximizers and two subjects are privately rational. The third is when three subjects are social welfare maximizers and the remaining subject is privately rational. These solutions are calculated assuming each subject knows his type and the types of his cohorts.

In the Nash-200 experiments, the social welfare maximizing subject has insentive to contribute 62 tokens to the group exchange regardless of the contribution levels of his cohorts. So, let (n) be the number of privately rational subjects in the experiment, leaving (4 - n) social welfare maximizers. Let Y_p and Y_s be the symmetric privately rational and social welfare maximizing investment levels respectively. The (n) privately rational subjects must satisfy:

$$nY_p = 200 - (4 - n)Y_s \text{ or } Y_p = 200/n - (4 - n)/n\ 62.$$

Yielding,

$$Y_P = 46, \; Y_S = 62 \quad \text{for } n = 3$$
$$Y_P = 38, \; Y_S = 62 \quad \text{for } n = 2$$
$$Y_P = 14, \; Y_S = 62 \quad \text{for } n = 1$$

In the Nash-48 experiments, the privately rational subject will invest in the group exchange to satisfy:

$$nY_p = 48 - (4 - n)Y_s. \qquad (4.15)$$

In addition, the social welfare maximizing subject will invest in the group exchange to satisfy:

$$(4 - n)Y_s = 198 - nY_p. \quad (4.16)$$

Case 1: $n = 1$

From the endowment constraint, $Y_p \leq 62$. Substituting this into equation (4.16) yields $3Y_S \geq 136$. Thus, equation (4.15) becomes $Y_p \leq -88$ or $Y_p = 0$; yielding $Y_s = 62$.

Case 2: $n = \{2, 3\}$

From the endowment constraint, Y_s is non-negative, so from equation (4.15) $nY_p \leq 48$. Substituting $nY_p \leq 48$ into equation (4.16) yields $(4 - n)Y_s \geq 150$. Imposing the token constraint yields, $Y_s = 62$ and $Y_p = 0$ for $n = \{2, 3\}$.

Summarizing, social welfare maximizing and privately rational agents will invest along their respective best-response functions. If they all forecast cohort group exchange investment levels accurately, then they will achieve one of the two symmetric solutions or one of the three mixed solutions. These solutions are characterized by strategy and summarized in Table 2.

V. The Analysis Of Results

In addition to following a best-response path, subjects having solved one of the five solutions might unilaterally play that solution and wait for cohorts to converge to the anticipated solution. Thus, the experimental environment yields two broad behavioral categories for investment in the group exchange investment.

1) Individual providers invest into the group exchange as predicted by one of their best-response functions.

2) Individual providers myopically invest tokens into the group exchange as predicted by one the five solution types.

The predicted outcomes associated with these two categories and the underlying maximization problems can be compared to the outcomes achieved by subjects participating in the experimental decision environment.

$$(4 - n)Y_s = 198 - nY_p. \qquad (4.16)$$

Case 1: n = 1

From the endowment constraint, $Y_p \leq 62$. Substituting this into equation (4.16) yields $3Y_S \geq 136$. Thus, equation (4.15) becomes $Y_p \leq -88$ or $Y_p = 0$; yielding $Y_s = 62$.

Case 2: n = {2, 3}

From the endowment constraint, Y_s is non-negative, so from equation (4.15) $nY_p \leq 48$. Substituting $nY_p \leq 48$ into equation (4.16) yields $(4 - n)Y_s \geq 150$. Imposing the token constraint yields, $Y_s = 62$ and $Y_p = 0$ for n = {2, 3} .

Summarizing, social welfare maximizing and privately rational agents will invest along their respective best-response functions. If they all forecast cohort group exchange investment levels accurately, then they will achieve one of the two symmetric solutions or one of the three mixed solutions. These solutions are characterized by strategy and summarized in Table 2.

V. The Analysis Of Results

In addition to following a best-response path, subjects having solved one of the five solutions might unilaterally play that solution and wait for cohorts to converge to the anticipated solution. Thus, the experimental environment yields two broad behavioral categories for investment in the group exchange investment.

1) Individual providers invest into the group exchange as predicted by one of their best-response functions.

2) Individual providers myopically invest tokens into the group exchange as predicted by one the five solution types.

The predicted outcomes associated with these two categories and the underlying maximization problems can be compared to the outcomes achieved by subjects participating in the experimental decision environment.

A summary of these comparisons show that of the 76 subjects participating in the 19 experiments, 49 (64%) followed group exchange investment strategies consistent with one of the two investment categories. Another 12 (16%) subjects followed an investment strategy of equally dividing tokens between the two exchanges and the final 15 (20%) subjects' investments into the group exchange were inconsistent with all of the above.

These summary results were compiled from subject type sorting procedures derived from the two categories of subject investment. The first classification scheme sorted for subjects following one of their best-response paths. The second classification scheme sorted for subjects myopically following one of the five solution types. For reporting purposes, a subject whose investment path followed a best-response path and also followed a myopic solution path was classified according to the best response scheme.

Best Response Classifications. Social welfare maximizing subjects must invest in the group exchange as predicted by equations 4.5 or 4.6 and Nash type subjects must invest as predicted by equations 4.14 or 4.15. These best-response functions are dependent on cohort group exchange investment levels. Thus, in order to choose a best response the subjects must first forecast their cohort's group exchange investments. In a subset of the experiments, these forecasts were expressly solicited from the subjects. In the remaining experiments, a forecast mechanism must be assumed. For the purpose of this analysis, the subjects were assumed to forecast cohort group exchange investment levels perfectly.

Perfect Foresight. Given this forecast mechanism, the subjects' best-response functions generate a pair of predicted group exchange investment paths. One best-response path associated with social welfare maximizing and one associated with Nash behavior. Each subject's actual investment path was paired, period by period, with the two perfect foresight best-response paths. The Wilcoxon matched pairs test was used to determine whether a subject's investment path was significantly-different from the predicted best-response paths, at a significance level of a = 0.05. In cases where the best-response path was at a corner solution for all 10 investment rounds the one-tailed matched pairs t-test was used[6] for classifying subject type[7].

Using this procedure, the subjects were sorted into one of three types.

1) Nash type providers, for those subjects whose investment path was not significantly different from the Nash best-response path.

2) Social type providers, for those subjects whose investment paths were not significantly different from the social welfare maximizing best-response path.

3) None, for those subjects whose investment paths were significantly different from both best-response paths.

Table 3 reports the results of this classification process. As seen in the third column, of the 76 subjects participating in the provision experiments, 23 (30%) invested tokens into the group exchange in a way consistent with the Nash best-response path and 11 (14%) invested in a way consistent with the social welfare maximizing best-response path.

These results come from pooling ten Nash-200 and nine Nash-48 experiments. As Isaac and Walker (1992) found asymmetric investment results between these two experimental treatments, it is useful to look

---

[6]The Wilcoxon test was inappropriate since all ranks would be constrained either positive or negative. Therefore, the minimum of the sum of the positive or negative ranks would be zero. The test would always reject the hypothesis that the actual investment path and the best response path have the same distribution. The t-test will suffer due to the truncation in the data and will tend to over reject but is more robust in this environment.

[7]In addition, for one subject in the Nash-48 experiments, due to cohort investment patterns, the Nash and social welfare best response paths were identical. This subject was arbitrarily classified as a Nash type provider.

closer for corresponding asymmetries in subject type results.

The 40 subjects in the Nash-200 experiments, reported in the first column of Table 3, invested so that 11 (28%) of the subjects fit the classification of Nash type providers and 9 (22%) as social welfare maximizing actors. Figure 1a records the average per-period deviations from the best-response path (BRP) for those classified as Nash actors or social actors. As seen, the social welfare maximizing actors closely track their BRP. The Nash actors' path is more erratic, but the BRP reference line is a good estimate of central tendency.

Of the 36 subjects in the Nash-48 experiments, reported in column 2 of Table 3, 12 (33%) of the subjects fit the classification of Nash type actors, 2 (6%) fit the classification of social welfare maximizing actors. Figure 1b shows the average deviation from the BRP for the Nash-48 experiments. Though the average deviations track the BRP less closely in Figure 1b than in Figure 1a, they still show a tendency toward the BRP. Thus, adding modest support to the classification results.

The particular classification scheme, described above, suggests there are fewer social welfare maximizing actors in the Nash-48 experiments than in the Nash-200. A more detailed investigation of this and other differences will be presented when the experimental treatment effects are examined.

<u>Forecasting Experiments.</u> In the experiments where forecasts were solicited, it was possible to construct the subject's best-response path given his reported forecasts. Thus, the determination of a subject's underlying paradigm of rationality was not contingent upon an assumed forecasting mechanism.

There were 6 forecasting experiments. As reported in last column of Table 4, of the 24 subjects who participated in these experiments, 5 (21%) followed a strategy not significantly different from their Nash best-response paths. The first column of Table 4 reports 3 (25%) of the

12 subjects who participated in the Nash-200 experiments followed Nash type strategies. The second column of Table 4 reports 2 (17%) of the 12 subjects who participated in the Nash-48 experiments followed Nash type strategies. None of the subjects were classified as following social welfare maximizing strategies.

Myopic Solution Classifications. It is interesting to note that 7 (58%) of the subjects in the Nash-48 forecasting experiments invested around 31 tokens into the group exchange. In all, 4 0 (57%) of their group exchange investments fell in the 3 token range from 30 to 32. This demonstrates the existence of a group of subjects whose investment strategy focuses on the midpoint of their endowment space. There are other potential focal points for investors. The second investment category addresses the issue of subjects myopically investing into the group exchange consistent with one of the five solution types reported in Table 2. A subject's actual group exchange investment path was compared to the predicted solutions. If the subject's investment path was sufficiently close, as determined by a paired t-test at a significance level of a = 0.05, to a theoretic outcome, that subject was classified as following the associated maximization problem[8]. For corner solution outcomes, the associated t-test was one tailed. For the others, the associated t-test was two tailed.

Using this sorting criteria, as seen in the third column of Table 5, 16 (21%) subjects' behavior was consistent with a social welfare maximizing path and 25 (33%) with a Nash path. Of the 35 (46%) subjects whose investment patterns were inconsistent with the solution paths, 14 (18%)[9] of them invested into the group exchange consistent with 31

[8]The t-test was used for consistency since the Wilcoxon test would be inappropriate due to corner solution problems for 10 of the 16 solution types.

[9]The difference between the number equal-dividers reported here and the number of equal-dividers reported in the summary is due to the fact that 2 of these agents have best response paths consistent with a mid-division strategy.

tokens; or equally dividing their token endowment between the two exchanges.

Nash-200 Experiments. Of the 40 subjects participating in the Nash-200 experiments, as seen in the first column of table 5, 19 (48%) were consistent with one of the Nash strategies and 12 (30%) with the social welfare maximizing strategy. Only 9 (22%) subjects failed to invest into the group exchange as predicted by one the solutions.

In all, 11 of 12 subjects classified as social welfare maximizers invested in the group exchange in a way not significantly different from the unique social optimum of 62 tokens. The top trace in Figure 2a shows how closely the "average per-period investments" of these 11 subjects came to the symmetric social optimum (SSO). Of the 110 investment decisions made by these 11 subjects, 92 (84%) were at 62 tokens and only 11 (10%) investment decisions were below 60 tokens yielding a distribution of group exchange investments tightly packed around 62 tokens.

A twelfth subject invested 62 tokens in the group exchange for each of his last five investment decisions. Although his investment path was significantly different from the socially welfare maximizing path, he was counted as being socially rational.

Of the 19 subjects classified as Nash agents, 12 invested in the group exchange not significantly different from the symmetric Nash equilibrium of 50 tokens. In addition, 5 followed an investment path consistent with the mixed subject solution with two social welfare maximizers and two Nash actors. The last 2 followed an investment path consistent with the mixed subject solution with one social welfare maximizer and three Nash actors. The middle trace in Figure 2a tracks the average per-period investment decisions of the 12 symmetric Nash subjects and shows how close they come to the symmetric Nash equilibrium (SNE) investment level. Of the 120 group exchange investments made by these subjects, 19% were at 50 tokens, and 45% fell within the 11 token investment level range of 45 to 55 tokens.

Nash-48 Experiments. Of the 36 subjects who participated in the Nash-48 experiments, shown in the middle column of Table 5, 6 (17%) behaved consistently with a Nash solution and 4 (11%) with a social welfare maximizing solution.

Three of the Nash type actors and 3 of the social welfare maximizers followed paths not significantly different from their respective symmetric solutions. In both cases the number of investments made at the symmetric solution levels, 50 tokens for social welfare maximizing and 12 tokens for Nash, were not significantly higher than expected by random investment at a = 0.05. This result raises questions as to whether the subjects were focusing their investment at these two solutions. Figure 2b shows how erratic the average investment paths are, and shows distinct downward trends. This is not consistent with the predictions of the symmetric solutions. The final 3 Nash type actors invested in a way not significantly above zero tokens, the mixed subject type Nash solution where at least one of the subjects is a social welfare maximizer. Of the 30 investment decisions made by these subjects, 25 were at zero tokens. This is strong evidence that these subjects were focusing their investments at zero tokens.

The average investment of 14 of the 26 remaining subjects was not significantly different from 31 tokens, with 64 (46%) of their 140 investment decisions in the 7 token mid-range from 28 to 34 tokens. Even though these subjects tended to invest 31 tokens into the group exchange, their per-period average investment had a definite downward trend toward the Nash equilibrium investment level of 12 tokens. In fact, their average per-period investment fell 8.5 tokens from 33.29 tokens to 24.79 tokens over the last five periods[10].

---

[10]In fact, the least squares linear approximation of these subjects' average investment path,

$$\text{Avg. Inv.} = \text{Intercept} + j3(\text{Period}) + v,$$
$$\text{where } v \sim n(0, a),$$

yields B = -0.94, significantly less than zero at a = 0.05 with a test

End Period Effects. Since the subjects in all of the experiments were explicitly informed that the experiments were ten periods, game theory suggests they should treat the last period as a one-shot voluntary contribution public goods game. Thus, subjects should invest into the group exchange as predicted by the solutions in Table 2. Over all, 16 (21%) of the end period investments matched a Nash investment and 15 (20%) matched a social welfare maximizing investment. Random investment suggests that 7 (9%) of investments should fall on one of the Nash solutions and 4 (5%) of investments should fall on one of the social welfare maximizing solutions. The Z-test for sample proportions show both Nash end-period investment and social welfare maximizing end-period investment significantly higher than predicted by random investment with Z-values of $Z = 3.61$ and $Z = 6.00$ respectively.

Treatment Effects on Subject Type. As forecasting is a new treatment in public good experiments, it is important to know whether it impacts subject behavior. An argument can be made that explicit forecasting induces subjects to focus on one of their two best-response functions. This added focus would result in higher proportions of subjects following one of their perfect foresight best-response paths. To test this hypothesis, a contingency table separating subjects by experimental design characteristics and behavior type was used. A 2-tailed Z-test of significance of difference between independent sample proportions was used to measure the impact of the design characteristic on subject behavior. The first test compares subject behavior in forecasting experiments to behavior in non-forecasting experiments, holding design characteristics constant through the contingency table.

Table 6 reports the Z-test statistics for the comparisons with the corresponding p-value in parentheses below. The first cell in Table 6 reports significantly (at $a = 0.05$) fewer social welfare maximizing

---

statistic of $t = -7.67$ and an intercept at 36.03. The negative coefficient B confirms the downward trend in the investment patterns of these subjects.

subjects in the forecasting experiments than in the non-forecasting experiments, holding the Nash-200 design constant. There are, also, fewer Nash actors and a significant increase in subjects following neither paradigm of rationality in the Nash-200 forecasting experiments than in the Nash-200 non-forecasting experiments. In the Nash-48 experiments (reported in the second column of Table 6) the forecasting treatment shows no significant effect on subject behavior. Thus, the proposition that forecasting would increase observed best response behavior can be rejected. If anything, forecasting in these experiments has a tendency to decreased proportions of subjects following a best-response path; contradicting the focusing effect that was expected.

The other experimental treatment in this study was the group exchange production function. Analyzing aggregate behavior, Isaac and Walker (1992) found an upward investment bias in Nash-48 experiments relative to a corresponding downward bias in the Nash-200 experiments. This implied that Nash equilibrium levels introduced a systematic effect which could not be entirely explained by random error. Given a systematic bias on group level investment associated with Nash equilibrium level, looking for effects associated with the Nash equilibrium at the individual level is a natural extension. Table 7 reports the Z-test values derived from testing the significance of difference in sample proportions of subject type classifications between the Nash-200 and Nash-48 experiments. The group exchange production function treatment shows no significant (at $a = 0.05$) nor consistent effect on subject behavior.

VI. Concluding Comments

This research investigated individual provision decisions in an experimental voluntary contribution public good environment. Subjects were classified according to the type of provision behavior they exhibited. Over all, 64% of the subjects participating in the public good experiments were classified as following one of the paradigms of rationality. The behavior of 43% of the subjects was consistent with Nash strategies and the behavior of 21% of the subjects was consistent with social welfare maximizing strategies. With one of five subjects following socially rational strategies, it is easy to see why, in aggregate, investment levels are significantly above those predicted by the Nash equilibrium.

Another 16% of the subjects (all from Nash-48) followed the strategy of equally dividing their token endowment between the group and private exchanges. As discussed in Section V, these subjects' investments trended downwards toward the Nash equilibrium level. This leaves 20% of the investment patterns unclassified.

The experiments had two treatment variables. The first was forecasting and the second was the Nash equilibrium level. The theory of objective maximizing agents is mute to these two treatments, implying they should have no effect on subject behavior. The effects of forecasting on the classification results was consistent across experiment type. Its observed impact on subject type classifications implies explicit forecasting hampers subjects from finding their perfect foresight best-response paths. The impact of Nash equilibrium level on subject behavior was not significant.

Over all, this investigation of individual level behavior extends our understanding of aggregate level results presented in past studies of the voluntary contribution mechanism for public goods. In particular, it shows that a large proportion of the subjects have public good contribution patterns consistent with theoretic predictions. It also shows that Nash type behavior is not the dominant behavior in this environment, with a full 57% of the subjects exhibiting non-Nash behavior. Although neither aggregate Nash nor aggregate socially optimal behavior is observed, the observed behavior of most subjects is consistent with one of the two underlying paradigms of rationality.

APPENDIX A Transcript of Instructions

This experiment is a study of group and individual exchange behavior. The instructions are simple, and if you follow them carefully and make good investment decisions, you may earn a CONSIDERABLE AMOUNT OF MONEY which will be paid to you in cash at the end of the experiment. Various research foundations have provided funds for this research.

You are one person in a group of 4. Each of you will be given an investment account with a specific number of tokens in it. All tokens must be invested to turn them into income.

There are two ways you can earn money by investing your tokens. Press -NEXT- to find out more about them.

1. The INDIVIDUAL EXCHANGE

For each token you invest in the individual exchange you get: 1 Cents per token.

For example:

If you invest 55 tokens in the individual exchange, you earn: $ 0.55.

If you invest 140 tokens in the individual exchange, you earn: $ 1.40.

2. The GROUP EXCHANGE

The return on your investment in the group exchange is not so easily determined.
Your earnings depend upon the total investment in the group exchange (your invested tokens plus all of the other tokens invested by the other people in your group).

Press NEXT to find out more about the group exchange; press BACK to review the previous instructions.

You and 3 other people are members of a group.

When you invest in the group exchange, how much money you get back depends on what <u>you</u> do and also on how much the other group members invest.

The more the <u>GROUP</u> invests, the more you all get from the <u>GROUP</u> exchange.

In your group, each person has an investment account with a specific number of tokens in it.
The group as a whole has 248 tokens.
YOU have 62 tokens .

When you invest in the group exchange, the tokens you invest are no longer yours. THEY BECOME THE PROPERTY OF THE GROUP!

The money that the invested tokens earn is also the property of the group. This money is divided up at the end of the period. Each person gets an equal share out of every group dollar.

IT DOES NOT MATTER WHO INVESTS THE TOKEN IN THE GROUP EXCHANGE. Every dollar is divided up this way.

For example:
If you put no tokens in the group exchange, but the other members invest enough to earn $1.00, you earn 25 cents from the group exchange.

If the others invest no tokens in the group exchange, but you put in enough for the group to earn $1.00, you still earn 25 cents from the group exchange.

REMEMBER - how much you and the other group members earn depends on how much all of you together put into the group exchange.

Press -NEXT- to see the Payoff Table for the Group Exchange
-BACK- to Review

Tokens invested in the GROUP exchange by ___ group members	Total money earned by THE GROUP $	How much money YOU EARN $
0	0.00	0.00
16	0.77	

You and 3 other people are members of a group.

When you invest in the group exchange, how much money you get back depends on what <u>you</u> do and also on how much the other group members invest.

The more the <u>GROUP</u> invests, the more you all get from the <u>GROUP</u> exchange.

In your group, each person has an investment account with a specific number of tokens in it.
The group as a whole has 248 tokens.
YOU have 62 tokens .

When you invest in the group exchange, the tokens you invest are no longer yours. THEY BECOME THE PROPERTY OF THE GROUP!

The money that the invested tokens earn is also the property of the group. This money is divided up at the end of the period. Each person gets an equal share out of every group dollar.

IT DOES NOT MATTER WHO INVESTS THE TOKEN IN THE GROUP EXCHANGE. Every dollar is divided up this way.

For example:
If you put no tokens in the group exchange, but

the other members invest enough to earn $1.00, you earn 25 cents from the group exchange.

If the others invest no tokens in the group exchange, but you put in enough for the group to earn $1.00, you still earn 25 cents from the group exchange.

REMEMBER - how much you and the other group members earn depends on how much all of you together put into the group exchange.

Press -NEXT- to see the Payoff Table for the Group Exchange
-BACK- to Review

Tokens invested in the GROUP exchange by group members	Total money earned by THE GROUP $	How much money YOU EARN $
0	0.00	0.00
16	0.77	0.19
32	1.48	0.37
48	2.15	0.54
64	2 .76	0.69
80	3.33	0.83
96	3.84	0.96
112	4.30	1.08
128	4. 71	1.18
144	5.07	1.27
160	5.38	1.34
176	5.63	1.41
192	5.84	1.46
208	5. 99	1.50
224	6.09	1.52
240	6.14	1.54
248	6.15	1.54

Example:
Suppose that the members of your group together invest a total of 128 tokens in the group exchange.
Look in the table at the line beginning with the number of tokens closest to this total. The appropriate values are underlined. (Press DATA to view the table.)

Tokens invested in the GROUP exchange by group members	Total money earned by THE GROUP $	How much money YOU EARN $
0	0.00	0.00
16	0.77	0.19
32	1.48	0.37
48	2.15	0.54
64	2.76	0.69
80	3 .33	0.83
96	3.84	0.96
112	4.30	1.08
128	4.71	1.18
144	5. 07	1.27

160	5.38	1.34
176	5.63	1.41
192	5.84	1.46
208	5.99	1.50
224	6.09	1.52
240	6.14	1.54
248	6.15	1.54

Look to the underlined values.

You saw from the table that the group gets $ 4.71. from the exchange. Every group member gets $ 1.18. from the exchange.
You would receive $ 1.18 from the group exchange.
WHETHER OR NOT YOU DEPOSIT ANY OF YOUR TOKENS IN THE EXCHANGE!

When you invest, you can divide your tokens in any way you want. That is, you can:

a. put all of them into the group exchange
b. put all of them into the individual exchange
c. put some of them into the group exchange and some of them into the individual exchange.

You will have 10 Trials in which you make investment decisions. The profits you make are stored after each Trial and the total profits from all Trials paid to you at the end of the Experiment.

When you are asked how you want to invest, you may put all, some, or none of your 62 tokens in the group exchange, and put the remaining tokens in the individual exchange. After you and everyone else in your group has had a chance to invest at this first stage, you will be shown how many of the group's 248 tokens have been put in the group exchange, and how many have been put into the individual exchange. You will also be told your earnings from the group exchange, from the individual exchange, and your total earnings.

To give you practice in entering your investments, let's go through an example. Your screen will show the same information it will contai7 in the actual experiment. Only the directions in the box will not be available during the experiment.

You will be able to view your earnings from each of the previous TRIALS at the beginning of a new investment TRIAL. Press -DATA- to view the tables now.

TOTAL INVESTED	TRIAL 1	2	3	4	5	6	7	8	9
grp	124	117	123	120	100	116	138	123	131
ind	124	131	125	128	148	132	110	125	117

The token investment behavior of the group will be totaled and shown in the table above.

YOUR PROFIT	TRIAL 1	2	3	4	5	6	7	8	9
grp	1.1	1.1	1.1	1.1	0.9	1.1	1.2	1.1	1.20
ind	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.62
Total	1.7	1.7	1.7	1.7	1.6	1.7	1.8	1.7	1.82

The profit level from each TRIAL will be entered in the TABLE above.

Press BACK to return to the investment page.
Profits at the end of Trial (9)= $17.70

You have 62 tokens.

Suppose you decide to put 32 tokens in the group exchange.

How many tokens do you wish to invest in the group exchange? > 32
Press EDIT to correct or change your bid; press NEXT to enter your bid.

Type 32 after the arrow, then press NEXT to enter your answer.

Now you have 30 tokens left to invest in the individual exchange. Press NEXT to continue display.

How many tokens do you wish to invest in the individual exchange? > 30

Your group and individual investments together must total 62 . You must invest all of your tokens.
Press EDIT to correct or change your bid; press NEXT to enter your bid.

Type 30 after the arrow, then press NEXT to enter your answer.

If you wish to change your investment decision at this time, press shift-BACK and redo the investment process. If you are satisfied with your decisions,

At this point, you can press shift-BACK to change your investment decisions for this period. You may do so now if you wish to review the practice trial up to these instructions. If you understand the procedures so far, press NEXT.

RESULTS

You earned $ 1.18 from the group exchange.
You earned $ 0.30 from the individual exchange.
Total earnings = $ 1.48

Total token investment in group exchange = 128
Total token investment in individual exchange = 120

IMPORTANT NOTICE

REMEMBER: At the end of the experiment you receive the sum of your profits from all TRIALS.

DO NOT SPEAK TO ANY OTHER PARTICIPANT!

The individual exchange gives you a sure return. Also, you have a chance to earn money from the group exchange if any members invest in it.

The group exchange gives you a chance to make more from your tokens invested. But, the earnings from the Group Exchange will depend on the investment decision of all participants.

NOTE: Your individual decision on how much you invest in the private exchange and in the group exchange is not known by the other participants. Only information on total group investment is given to each person.

Do not press NEXT until you are ready to enter the experiment. Once you press NEXT you will not be able to review the instructions. Press BACK to review the instructions in reverse order; press shift-BACK to review the instructions in their entirety; press NEXT only if you understand all of the instructions.

You will not be able to return to the instructions after leaving this page. If there is any doubt in your mind press BACK.

Once you press NEXT there is no turning back. Press NEXT only if you fully understand the instructions.

ADDITIONAL INSTRUCTIONS

Please read these carefully

At the end of each investment period the computer will display a screen which shows the results of the recently completed period. After viewing the results you can move into the next decision period. Once you have entered the next decision period, you have many options. These include reviewing the history of decisions, entering a screen which allows you to calculate potential scenarios, and investing in the current period.

Before making your investment decision, you are to make a prediction on what you think the total investment of the others will be in the **group account.** Your prediction of the others investment will be the total investment you anticipate in the group account minus what you plan to invest in the group account. You will then write this number down beside the appropriate period on the sheet provided for you.

An example: If you intend to invest 20 tokens in the group account in period 1 and you expect the total investment in the group account to be 80 tokens in period 1, then the amount you expect the others to invest in period 1 will be 80 - 20 = 60. You would then write 60 in the space beside period 1 on the worksheet provided.

REMEMBER: It is important that you record **only** the investment in the **group account** you **expect the others** to make.

At the end of the experiment an investment period will be randomly selected and the individual whose prediction of the total market-2 investment of others is closest to the actual for that period will receive an additional $3.00. This payment will be divided for ties.

Table 1	**Experimental Treatments**			
	Experiment Type			
	Nash-200		Nash-48	
Group Exch. Payoff Ftn.	$g(Y) = 8Y - .01(Y)^2$		$g(Y) = 4.96Y - .01(Y)^2$	
Number of Experiments	10		9	
Number of Subjects	40		36	
	No Forecasts	Forecasts	No Forecasts	Forecasts
Number of Experiments	7	3	6	3
Number of Subjects	28	12	24	12

Table 2	**Individual Contribution Level Solutions**	
Subject Type and Subject Mix	Experiment Type	
	Nash-200	Nash-48
0 Nash 4 Soc	62 tokens	49, 50 tokens
1 Nash 3 Soc	14 tokens 62 tokens	0 tokens 62 tokens
2 Nash 2 Soc	38 tokens 62 tokens	0 tokens 62 tokens
3 Nash 1 Soc	46 tokens 62 tokens	0 tokens 62 tokens
4 Nash 0 soc	50 tokens	12 tokens

Table 3	Number of Individuals Investing in a Way Not Significantly Different From One of their Best Response Functions Under the Perfect Foresight Assumption.		
	Experiment Type		
	Nash-200	Nash-48	Total
Social Wel. Max.	9 (22%)	2 (6%)	11 (14%)
Privately Rational	11 (28%)	12 (33%)	23 (30%)
Neither	20 (50%)	22 (61%)	42 (55%)

Table 4	Number of Individuals Investing in a Way Not Significantly Different From One of their Best Response Functions Given Actual Forecast Data.		
	Experiment Type		
	Nash-200	Nash-48	Total
Social Wel. Max.	0 (0%)	0 (0%)	0 (0%)
Privately Rational	3 (25%)	2 (17%)	5 (21%)
Neither	9 (75%)	10 (83%)	19 (79%)

For one of the subjects assigned as privately rational in the Nash-200 experiments, the social and Nash best-response paths were identical. This subject was arbitrarily assigned as privately rational.

Table 5 Number of Individuals Investing in a Way Not Significantly Different From One of the Five Symmetric Solutions.

	Experiment Type		
	Nash-200	Nash-48	Total
Social Wel. Max.	12 (30%)	4 (11%)	16 (21%)
Privately Rational	19 (48%)	6 (17%)	25 (33%)
Neither	9 (22%)	26 (72%)	35 (46%)

Table 6 Impact of Forecasting on Individual Behavior. Z-test Measuring the Significance of Difference Between Two Independent Sample Proportions: Comparing Forecasting Experiments to Non-Forecasting Experiments Under Perfect Foresight

	Experiment Type	
	Nash-200	Nash-48
Social Wel. Max.	-2.22 (0.03)	-0.99 (0.32)
Privately Rational	-1.82 (0.07)	0.00 (1.00)
Neither	3.48 (0.00)	0.52 (0.60)

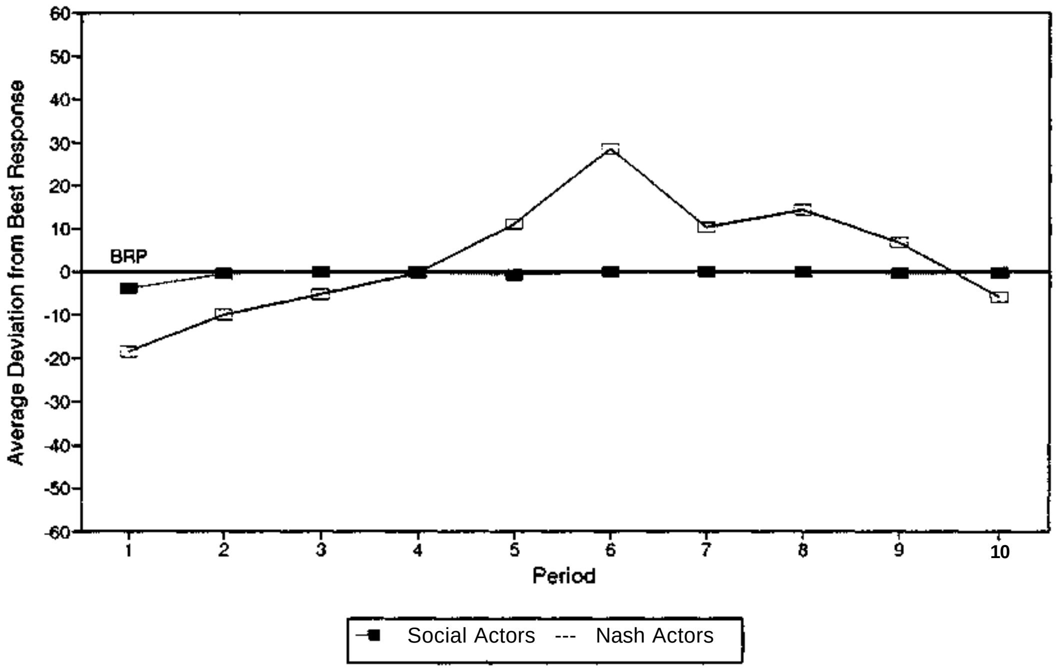
Table 7 Impact of Nash Equilibrium Level on Individual Behavior. Z-test Measuring the Significance of Difference Between Two Independent Sample Proportions Comparing Nash-200 Experiments to Nash-48 Experiments Under Perfect Foresight.

	Experiment Type	
	Forecast	Non-Forecast
Social Wel. Max.	N/A	2.11 (0.03)
Privately Rational	-1.51 (0.13)	0.23 (0.82)
Neither	1.51 (0.13)	-1.88 (0.06)

N/A indicates sample proportions are both zero and, thus, the test is undefined.

Figure 1

1a: Nash-200 Average Deviation from the
Perfect Foresight Best Response Paths



1b: Nash-48 Average Deviation from the
Perfect Foresight Best Response Paths

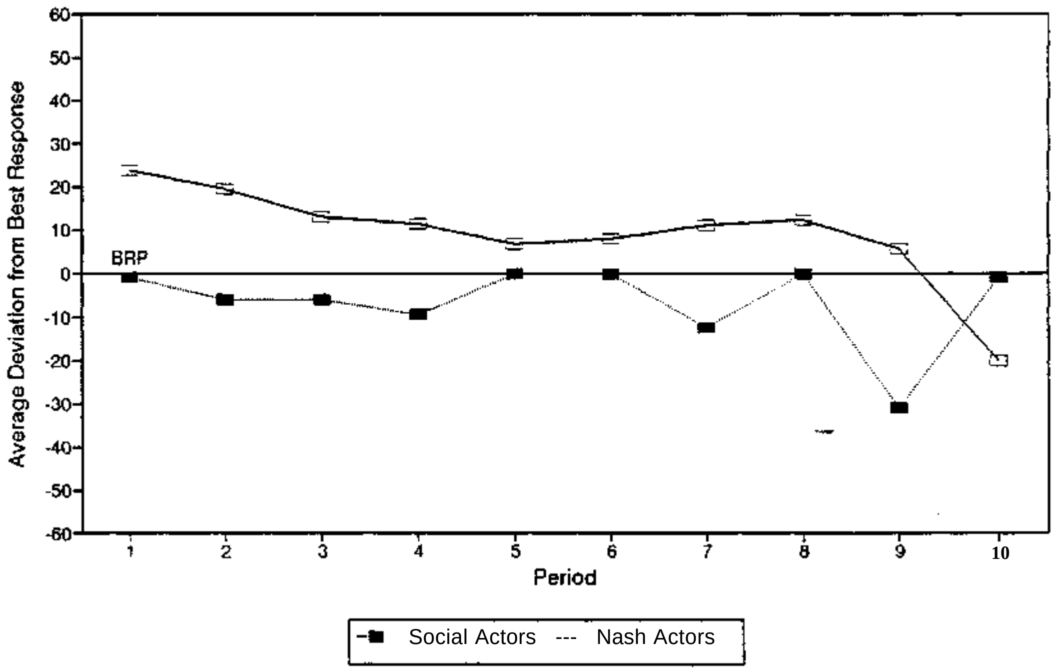
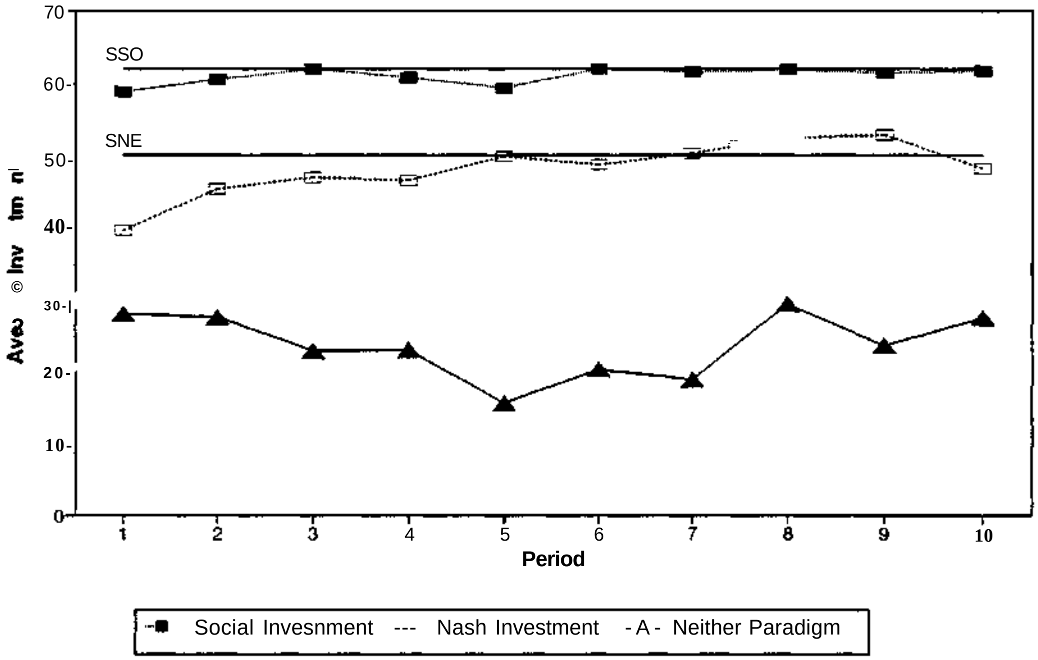
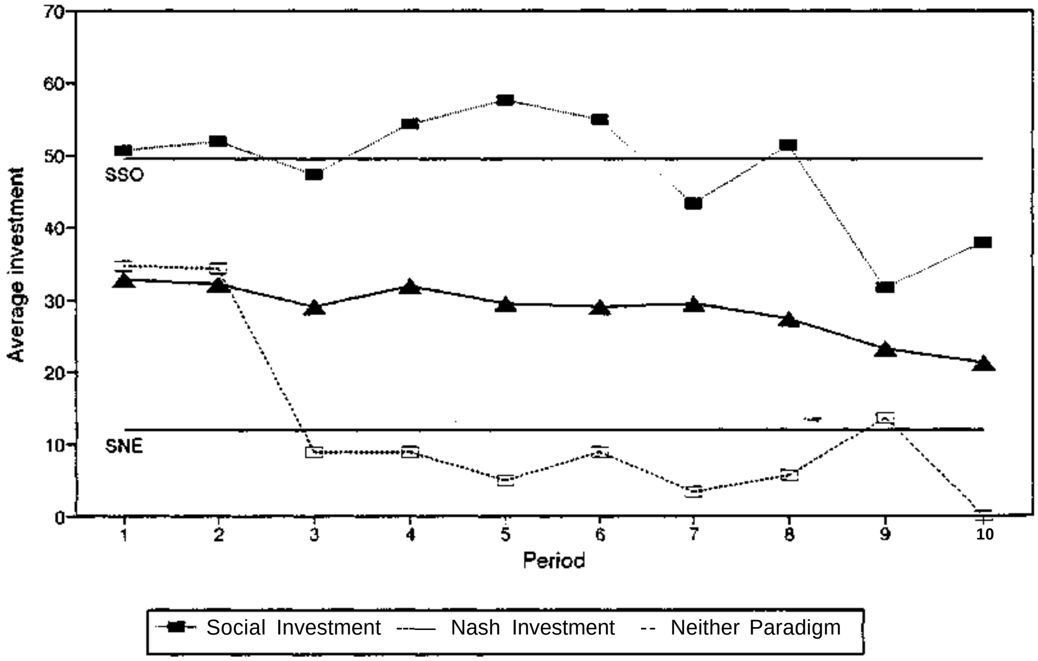


Figure 2

2a: Nash-200 Average Investment Path of
Subjects Classified as Following
One of the Symmetric Solutions



2b: Nash-48 Average Investment Path of
Subjects Classified as Following
One of the Symmetric Solutions



CHAPTER 3

INDIVIDUAL CHOICE IN COMMON POOL RESOURCE ENVIRONMENTS: AN EXPERIMENTAL APPROACH

I. Introduction

It is traditional to view the appropriation problem faced by individuals in a Common Pool Resource (CPR) under the framework laid out in The Economic Theory of a Common Property Resource: The Fishery (Gordon 1954). In this framework, appropriators face the pressures from an open access resource and a competitive output market. These pressures lead the appropriators to allocate the factors of production, used for exploiting the resource, in a socially sub-optimal manner. The appropriators over employ inputs to the CPR from a social planner's point of view.

In cases where CPR communities aggressively protect their resource from outside entrants, a limited access model of CPR exploitation is more appropriate. However, even in cases where the boundary restrictions limit access, a model based on non-cooperative Nash type behavior, again, predicts over employment of inputs to the CPR (Clark 1980).

Thus, models based on appropriators equating marginal private benefits to marginal private costs (private rationality) predict input employment patterns in a CPR environment different from models based on social welfare maximizing appropriators. This study investigates observed appropriator input employment in an experimental CPR environment[1]. The focus is on whether an appropriator's input employment in the CPR is consistent with the predictions made under the theoretic assumption of privately rational appropriators or the

[1]This study reexamines the symmetric Nash design experiments described in Walker, Gardner and Ostrom (1990).

theoretic assumption of social welfare maximization appropriators.

Walker, Gardner and Ostrom (1990) found sub-optimal CPR aggregate input employment levels in their limited access CPR experiments. They also found that aggregate input employment, in many experiments, approximated aggregate Nash equilibrium levels, but in none of their experiments was the Nash equilibrium played. This study uses the individual level data from the Walker, Gardner and Ostrom (1990) experiments along with the data from a set of forecasting experiments to investigate individual level input employment choices. The input employment choices made by the appropriators in these experiments were compared to the outcomes predicted by the competing paradigms of human behavior to determine the appropriator's decision process.

The next section of this paper develops the theoretical framework of the appropriation problem in a CPR. Sections III and IV describe the experimental environment. Sections V and VI analyze the experimental results and section VII presents concluding comments.

II. The CPR Appropriation Problem

The decision problem faced by appropriators in a limited access CPR is the choice of input employment levels. The environment in which these decisions are made is as follows.

1. There are N potential appropriators.
2. The appropriators are each endowed with Y° units of an input that they can use in the CPR.
3. They each use $Y_i \in [0, Y^\circ]$ units of the input in the CPR, leaving $(Y^\circ - Y_i)$ units of the input to employ in an outside competitive endeavor.
4. The outside endeavor has a constant marginal return to input use of C.
5. Input use Y_i employed in the CPR yields an output to the appropriator of Q_i such that, $Q_i = f(Y_i, Y^T)\, g(Y^T)$; where,

A. Y^T is the aggregate input level in the CPR.

B. $g(Y^T)$ is the aggregate CPR output.

C. g() is bounded above by the CPR's stock and eventually exhibits diminishing marginal returns,

D. $f(Y_i Y^T)$ determines appropriator i's proportion of the aggregate output. Where $f(Y_i, Y^T)$ e [0,1] and $E^N_{i=1} f(Y_i, Y^T) = 1$.

6. The appropriator is paid P^c the competitive output price for each unit of output Q_i he sells.

The Privately Rational Appropriator. Within this framework the appropriator has a private profit function of

$$\wedge(Y_i Y^T) = P^C Q_i + C(Y^\circ - Y_i)$$
$$= f(Y_i, Y^T)\ g(Y^T)\ P^c + C(Y^\circ - Y_i)\ , \qquad (2.1)$$

and the maximization problem

$$\max_{Y_i}\ f(Y_i, Y^T)\ g(Y^T)\ P^c + C(Y^\circ - Y_i)\ . \qquad (2.1a)$$

This problem is solved when the appropriator employs inputs (Y_i) in the CPR to the point where

$$P^c \left[f() \frac{dg()}{dY^T} \frac{dY^T}{dY_i} + g(Y^T) \left[\frac{\partial f()}{dY_i} + \frac{df()}{dy^T} \frac{dY^T}{dY_i} \right] \right] - C = 0. \qquad (2.2)$$

In an open access environment, a single appropriator has negligible influence over aggregate input employment. If $f(Y_i Y^T) = Y_i / Y^T$, then equation (2.2) reduces to

$$\frac{g(Y^T)}{Y^T} P^c = C, \qquad (2.3)$$

implying the appropriators employ factors of production in the CPR to the point where the average revenue product (ARP) of the inputs equal their marginal costs (MC). This is Gordon's complete rent dissipation result.

In the limited access environment, privately rational appropriators face the maximization problem described by equation (2.1a), yielding the first order profit maximizing condition described by equation (2.2). Assuming the individuals have myopic Nash conjectures[2], $\frac{dY^T}{dY_i} = 1$, then privately rational appropriators employ inputs in the CPR to the point where

$$P^c \left[f() \frac{dg()}{dY^T} + g(Y^T) \left[\frac{Y^T - Y_i}{(Y^T)^2} \right] \right] = C. \qquad (2.4)$$

Equation (2.4) implies that an individual appropriator, following Nash incentives, will choose to employ inputs to the point where the marginal impact of another personally employed input to the CPR on his private revenue is equal to the marginal cost of that unit of effort. This appropriator ignores the effect his input employment decision has on the inputs employed by his cohorts in the CPR and over employs factors of production in the CPR.

It is important to note that Nash conjectures are not consistent conjectures in a CPR environment (Mason, Sandier and Cornes, 1988) . I will use the consistent conjectural variation solution as another privately rational paradigm. As in Perry (1982), this study will only consider consistent conjectures at symmetric equilibria[3].

In symmetric equilibrium $Y_i = \frac{Y^T}{N}$ so equation (2.2), the profit maximizing condition, becomes the equilibrium condition

$$P^c \left[\frac{1}{Y^T} g(Y^T) \left[1 - \frac{1}{N} (1 + 8) \right] + g'(Y^T) \frac{1}{N} (1 + 8) \right] - C = 0 \qquad (2.5)$$

where 8 is an appropriator's conjecture as to the effect of his input employment decision on the employment decisions of others. This conjecture is consistent when it is equivalent to the observed sensitivity of cohort input employment. That is, 8 must equal the cohorts' responsiveness to an anticipated out of equilibrium input employment level by the individual. Implicitly differentiating the

---

[2]The Nash conjecture implies that individual appropriators assume that marginal changes in their investment patterns have no impact on the expected investment patterns of cohort appropriators. That is, $dy_j/dy_i = 0$ for all j = i.

[3]This is because the agents participating in the experiments are facing identical decision environments.

equilibrium condition with respect to Y_i to find $d(\Sigma_{j \neq i} Y_j)$ (the cohort's responsiveness to an anticipated input employment level) and solving for the fixed point where,

$$\delta = \frac{d(\Sigma_{j \neq i} Y_j)}{dY_i}$$

yields

$$-P^c \left[\frac{1}{Y^T} g(Y^T) - g'(Y^T) \right] \left[1 - \frac{1}{N}(1+\delta) \right] (1+\delta) + g''(Y^T) P^c \frac{(1+\delta)^2}{N} = 0$$

and a trivial fixed point solution at $(1+\delta) = 0$, or $\delta = -1$. This translates to the individual assigning $\frac{dY^T}{dY_i} = 0$ in his best-response path. Using this consistent conjecture, equation (2.2) reduces to equation (2.3), or under consistent conjectures the appropriators employ inputs in the CPR to the point of total rent dissipation.

Thus, private rationality lends credence to two types of limited access behavior. The first described by equation (2.4), Nash behavior, and the second described by equation (2.3), average revenue equalization.

The Social Welfare Maximizing Appropriator. The social welfare maximizing appropriator acts to maximize the CPR's joint profit function. This yields

$$\max_{y_i} \Sigma_{i=1}^{N} (Y_i; Y^T) = \max_{y_i} g(Y^T) \; P^c + C(NY^\circ - \Sigma_{i=1}^{N} Y_i), \qquad (2.6)$$

and the first order condition of

$$P^c \frac{dg()}{d\,\cdot} = C. \qquad (2.6a)$$

In this case the individual employs inputs in the CPR to the point where the social marginal revenue product of the employed inputs equals its social marginal cost. Thus, social welfare maximization leads to a third type of behavior, that described by equation (2.6a).

III. The Experimental Environment

All experiments were conducted on the NovaNET computer network at Indiana University. The subjects participating in the experiments were volunteers from introductory microeconomics classes at Indiana

University. They were told they would participate in a computerized experimental economic decision environment and that their experimental earnings would depend upon their own decisions as well as the decisions of their cohorts.

The subjects were checked in and were assigned to NovaNET terminals through which they would receive instructions and participate in the decision environment. The subjects were forbidden to communicate one with another. Prior to reading the instructions the subjects were told they would be paid in cash, privately, at the conclusion of the experiment. If the subjects had any questions, they were told to direct them to the experiment monitor.

The computerized instructions (contained in Appendix A) explained the specifics of the particular decision environment in which the subjects would be working. In a subset of the experiments the subjects made one period ahead forecasts of their cohorts input employment levels. For these subjects, a page of supplementary instructions was handed out and read aloud by the experiment monitor to be sure all of the subjects understood the forecasting procedure. A copy of the supplementary instructions is included at the end of Appendix A.

The experiment was a multi-period game in which the subjects had to allocate an endowment of tokens between two experimental markets. (The CPR production function, the breakdown of experiments run and the length of these experiments is reported in Table 1.) These tokens were generic productive inputs for two different production processes (market-1 and market-2). The productive process in market-1 yielded one unit of output valued at five cents for each token invested. The output of the productive process in market-2 (the CPR) was contingent upon the aggregate level of tokens invested in market-2. An appropriator's share of the production from market-2 was strictly proportional to his investment of tokens (employment of inputs) in the production process. That is $f(Y_i Y^T) = Y_i/Y^T$. Each output from market-2 was valued at one cent.

An individual's payoff was the sum of his return from market-1 and market-2

$$r(Y_i, Y^T) = (Y_i) + 7r(Y_i, Y^T) = [5(Y^0 - Y_i)] + Y_i / y^T [aY^T - b[Y^T]^2]]^2]],$$

where i E {l,2,...,8}[4].

The subjects were informed of the specific parameters of the market-2 production function. They also had access to a table of values that summarized the production function through out the experiment. A subject's information set also included listing of personal earnings for each period from each market and the group token investment level in market-2. Their personal token investment and earnings history was accessible throughout the experiment.

The experiments were classified by three basic treatments. The first was experience level. Subjects participated in experiments with cohorts of similar experience in the decision environment. New recruits participated in experiments with other inexperienced cohorts. These subjects were then offered the opportunity to participate in another experiment with others who had been in at least one experiment. There was no experienced group which was made up entirely of participants from a single inexperienced experiment.

The second treatment was endowment level. There were two different endowment levels used in the experiments. The first was Y° = 10 tokens. Since the 10-token experiments yielded average revenue equalizing and Nash best-response paths that were often constrained by the endowment level, a set of 25-token experiments was run. Subjects participating in the 25-token experiments were told that they would be paid one half of their experiment earnings prior to participating in the experiment. This adjustment in payoff structure was to equalize subject earnings between 10-token and 25-token experiments at the Nash

---

[4]The quadratic production function was chosen for 2 basic reasons: The first is that it has the general bell shape yield associated with biological systems. Second it is analytically convenient.

equilibrium. Actual Nash equilibrium earnings in the 10-token experiments were 57% of those in the 25-token experiments. One half was a close and computationaly simple approximation. Subjects either participated in 10-token or 25-token experiments but not both.

The final treatment was forecasting. In a subset of the experiments the subjects were asked to forecast cohort market-2 token investment levels. In the 10-token experiments the subjects were not explicitly paid for their forecasts. This was to insure there was no incentive distortion caused by an additional payoff mechanism, thus allowing a direct comparison with the Walker, Gardner and Ostrom (1990) experiments. In the 25-token experiments, a period was randomly selected at the end of the experiment and the subject whose forecast was closest to their actual cohort token investment level was awarded an additional $3.00. This payoff scheme was selected because it did not distort the Nash nor the social welfare incentive structures[5].

IV. Theoretic Solutions

There are two theoretic frameworks that can be used to predict the outcomes of the experiments described in section III. Those two frameworks are the social welfare maximization paradigm and the paradigm of private rationality. Private rationality yields two competing models. The first is the Nash equilibrium model and the second is the consistent conjectures model that induces average revenue equalization. The sections below describe the particular predictions for these competing models, given the specific experiment parameters.

The Nash Model. When individuals act as Nash type agents, they strive to maximize their individual profit function subject to their beliefs of the aggregate token investment in market-2. Thus, their token investment strategy in market-2 must satisfy the necessary first

---

[5]This payoff structure does have an impact on the average revenue equalizing incentive structure. This impact is small so it is ignored in the analysis.

order condition

$$\frac{d(\ (Y_i)\ )}{dY_i} = a - 5 - 2bY_i - bY^T_{-i} = 0, \qquad (4.1)$$

where $\hat{Y}^T_{-i} = \hat{Y}^T - Y_i$ and $\hat{Y}^T$ is <u>anticipated</u> market-2 aggregate token investment. Solving for Y_i yields agent i's best response function

$$Y_i = \frac{(a - 5)}{2b} - 1/2(Y^T_{-i})\ . \qquad (4.2)$$

Inserting the parameter values used in the experiments for the market-2 production function, of a = 23, and b = 0.25, the best response function becomes

$$v^{BR}_i = \begin{cases} 0, & \text{if } Y_i < 0 \\ Y_i & \text{if } Y_i \in [0, Y^\circ] \subset I, \text{ where } Y_i = 36 - \tfrac{1}{2}\hat{Y}^T_{-i} \\ Y^0, & \text{if } Y_i > Y^\circ \end{cases} \qquad (4.3)$$

Thus, Y_i maximizes appropriator i's profits when his belief of the aggregate market-2 token investment is consistent with the actual market-2 token investment. A Nash equilibrium is achieved only when all agents' beliefs of group token investment levels are consistent with the actual levels. Since the individual agents in the experiment face the same revenue and cost structures, they have the same best response functions. Solving for the equilibrium condition results in

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

or,

$$Y^*_i = 8, \quad \text{for } i = \{1,2,...,8\}. \qquad (4.4)$$

Simply stated, there is a symmetric Nash equilibrium where all agents invest eight tokens in market-2. Note that this equilibrium solution is independent of the token endowment as long as the endowment of each individual includes the symmetric solution.

Average Revenue Equalization. Under the conjectural variations framework the individual appropriators act to equalize the average revenues between the two markets. Thus, they employ inputs such that

$$\frac{aY^T + b(Y^T)^2}{Y^T} = 5 \quad \text{or} \quad Y_i = \frac{5 - a}{b} - Y^T_{-i}$$

Which becomes

$$Y^{BR}_i = \begin{cases} 0, & \text{if } Y_i < 0 \\ Y_i, & \text{if } Y_i \in [0, Y^\circ] \subset I, \text{ where } Y_i = 72 - Y^T_{-i} \\ Y^0, & \text{if } Y_i > Y^\circ \end{cases} \qquad (4.5)$$

If all agents follow this strategy then a symmetric solution will exist where

$$Y_i = 72 - 7Y_i \quad \text{or} \quad Y_i = 9. \qquad (4.6)$$

Or, simply stated, all agents invest nine tokens in market-2. As with the Nash model this prediction is independent of whether the endowment is 25 tokens or 10 tokens.

Social Optimization. Under the paradigm of social welfare maximizing individuals, all individuals act to maximize joint welfare yielding the first order condition of

$$d\pi() = a - 5 + 2b\hat{Y}^T_{-i} + 2bY_i = 0. \qquad (4.7)$$

Solving for the best response function yields

$$Y_i = \frac{a - 5}{2b} - Y^T_{-i}, \qquad (4.8)$$

which becomes

$$Y_i^{BR} = \begin{cases} 0, & \text{if } Y_i < 0 \\ Y_i & \text{if } Y_i \in [0, Y^0] \subset I, \text{ where } Y_i = 36 - \hat{Y}^T_{-i} \\ Y^0, & \text{if } Y_i > Y^0 \end{cases} \qquad (4.9)$$

In a symmetric solution, each agent invests tokens to the point where

$$Y_i = \frac{a - 5}{2b} - 7Y_i \quad \text{or} \quad Y_i = \frac{a - 5}{16b}$$

$$\text{or} \quad Y_i^* = 4.5 \text{ tokens.} \qquad (4.10)$$

Since the experiment restricts the subjects to integer valued token investment levels, in both endowment treatment conditions, the agents must engage in a mixed strategy playing Y_i = 4 and 5, each with a probability of one half.

The three models of subject behavior yield three best-response functions derived from the optimization of the subject's underlying objective function. Objective optimizing individuals must invest tokens into market-2 as predicted by their associated best-response function. If all the subjects in a particular experiment share common objectives and forecast cohort market-2 token investment accurately, then one of the three symmetric solutions will be achieved.

V. Results: Subject Type Classification

The structure of the experimental environment yields specific individual market-2 token investment predictions. Subjects will invest tokens in accordance with the best-response function associated with their underlying optimization objective. In addition, subjects who have solved for a symmetric solution may unilaterally play that symmetric solution, waiting for the others to 'catch on'. Thus, the experimental environment yields two broad categories of market-2 token investments.

1) Individuals invest tokens as predicted by their respective best-response functions.

2) Individuals myopically invest 9 tokens for average revenue equalization, 8 tokens for Nash, and a mix of 4 and 5 tokens for social welfare maximization.

The predicted outcomes associated with these two categories of token investment are compared to the outcomes achieved by the subjects through their decision processes in the experiments.

A broad summary of the results of these comparisons reveals that, 170 (79%) of the 216 observed market-2 token investment paths were consistent with a path predicted by one of the two token investment categories. In all, 159 (74%) of the token investment paths were consistent with the underlying paradigm of private rationality and 11 (5%) of the token investment paths were consistent with the underlying paradigm of social welfare maximization.

These summary results were compiled from a two stage subject type sorting procedure that uses two classification schemes derived from the two market-2 token investment categories. The first classification scheme sorted subjects by their best-response paths. The second classification scheme sorted for subjects myopically following one of the symmetric solutions.

Best Response Classifications. An appropriator's best-response function, in each of the three behavioral models, is a function of the appropriator's anticipated cohort market-2 token investment level. Thus, an appropriator must forecast his cohorts' market-2 token investment level to determine his best response. In the first level of analysis, the best-response paths were calculated using the assumption that the subjects could perfectly forecast cohort market-2 token investment levels. In the forecasting experiments, a second analysis used best-response paths calculated using the subject's forecasts of cohort market-2 token investment levels.

To compare how closely appropriators came to investing tokens along their respective best-response paths, the sequences of best responses were calculated using the best-response functions described in equations (4.3), (4.5), and (4.9). These sequences were paired, period by period, with the observed token investment path of each of the appropriators. The Wilcoxon matched pairs test was used to determine whether the subjects' token investment paths were significantly different from any or all three of the best response paths at a significance level of a = 0.05[6]. In cases where the best response paths were constrained at a corner for each of the periods the Wilcoxon test would, by construct, always reject the hypothesis that two samples are drawn from the same underlying distribution, so the one tailed t-test was used because it is more robust about truncated data. In 21 cases the Wilcoxon test failed to reject two or more of the best response paths. In these cases the absolute proximity of the central tendency of the appropriator's actual token investment to the central tendency of the appropriator's predicted best response, and the number of agreements between token investment path and best-response path were

[6]The Wilcoxon test assumes independence between observations. The experiments were designed such that experimental parameters were independent across periods. Input employment decisions are dependent on both the experimental parameters and subject forecasts. To the extent forecasts are dependent across periods, the assumption of independence is violated. The assumption of perfect one-period ahead forecasting assumes away time dynamic forecasts. Thus, independence is assumed.

used to refine the rejection process[7].

Using this procedure, all the subjects were sorted into one of four categories.

1) **Average** type appropriators, for subjects whose token investment patterns were not significantly different from the average revenue equalizing best response predictions.

2) **Nash** type appropriators, for subjects whose token investment pattern was not significantly different from the Nash best response predictions.

3) **Social** type appropriators, for subjects whose token investment patterns were not significantly different from the social welfare maximizing best response predictions.

4) **None** for subjects whose token investment patterns were significantly different from the three previous.

The results of this classification procedure are reported in Table 2.

Perfect Foresight. Perfect-foresight forecasts were assumed in order to generate best-response paths in all of the 27 experiments. Over all, 128 (59%) of the 216 subjects were classified as following one of the three perfect-foresight best-response paths. Of these, 69 (32%) were classified as average revenue equalizers, 57 (26%) classified as Nash type appropriators and 2 (1%) classified as social welfare maximizers. Table 2 highlights a difference between 10-token experiments and 25-token experiments. The 25-token experiments have higher proportions of subjects following one of the best-response paths.

For the subjects participating in the 10-token experiments, summarized in the first major column of Table 2, 16 (12%) were average revenue equalizers and 33 (24%) were Nash type appropriators. Figure la plots the average per period deviation from the predicted best response for the subjects classified as Nash type appropriators and for the subjects classified as average revenue equalizers in the 10-token experiments. The reference line at '0' labeled BRP is the zero

---

[7]Thus, if, for example, the Wilcoxon test failed to reject that a particular investment path was significantly different from both the Nash and the average revenue equalization best response paths, then the theoretic path with the fewest absolute ties with the investment path and whose mean was farthest from the investment path's mean was rejected.

deviation path. Both the Nash type appropriators and the average revenue equalizers have average token investment paths that closely track their associated best-response paths.

In the 25-token experiments, as reported in the second major column of Table 2, 63 (66%) of the subjects were classified as average revenue equalizers, 24 (30%) classified as Nash type agents and 2 (3%) classified as social welfare maximizing agents. Figure lb traces the average deviations from best response path of the subjects classified as Nash type appropriators and as average revenue equalizers in the 25-token experiments. Here, the BRP reference line is a credible description of central tendency. The apparent downward trend in both traces, particularly for the average revenue equalizers' path, is not consistent with the predictions of either model of behavior.

Forecasting Experiments. In a subset of the experiments the subjects forecasted one period ahead cohort market-2 token investment levels. Using these forecasts to generate the subjects' best-response paths, it is possible to compare the subjects' actual token investment path to the predicted paths. Using the same classification technique as previously described, the subjects can be sorted as to their underlying type. The results of this process are reported in Table 3.

Overall, 66 (52%) of the 128 subjects invested tokens into market-2 consistent with one of the models of appropriator behavior. Of these, 36 (28%) were classified as average revenue equalizers, 28 (22%) as Nash appropriators and 2 (2%) as social welfare maximizers. In the 10-token experiments, summarized in the major first column of Table 3, 8 (11%) were classified as average revenue equalizers and 21 (29%) as Nash type appropriators. In the 25-token experiments, as reported in the second major column of Table 3, 28 (50%) were classified as average revenue equalizers, 7 (11%) as Nash type agents and 2 (4%) as social welfare maximizers.

Myopic Solution Classifications. The second category of market-2 token investment involves subjects myopically exploiting the CPR as predicted by one of the three symmetric solutions, even when the aggregate symmetric solution is not achieved. To test if a subject's token investment pattern was significantly different from one of the predicted symmetric solutions, a two-tailed t-test was used[8] at a significance level of a = 0.05. Using this procedure, all the subjects were sorted into one of four categories.

1) **Average** type appropriators, for subjects whose market-2 token investment patterns were not significantly different from 9 tokens, the symmetric average revenue equalizing prediction.

2) **Nash** type appropriators, for subjects whose market-2 token investment pattern was not significantly different from 8 tokens, the symmetric Nash equilibrium prediction.

3) **Social** type appropriators, for subjects whose Market-2 token investment patterns were not significantly different from 4, 5 tokens the social welfare maximizing symmetric solution.

4) **None** for subjects whose token investment patterns were significantly different from the three previous.

The results of this process are reported in Table 4.

Pooled over all experiments, 96 (44%) of the 216 subjects were classified as following one of the three symmetric solution paths. Of these, 33 (15%) were classified as following the symmetric average revenue maximizing solution path, 46 (21%) as following the symmetric Nash equilibrium token investment path, and 17 (8%) as following the social welfare maximizing solution.

In the 10-token experiments, summarized in the first major column of Table 4, 24 (18%) were classified as average revenue equalizers, 34 (25%) as Nash type appropriators and 9 (7%) as social welfare maximizers. Figure 2a reports the period by period average token investment of the subjects classified as either average revenue equalizers, Nash appropriators, or social welfare maximizers. It also indicates the three symmetric solutions as reference lines where SARE is

[8] The Wilcoxon test was not used because it tests whether two samples are drawn from a population with the same underlying distribution. The myopic solutions are point solutions and not a random sample. The t-test is more appropriate.

the symmetric average revenue equalizing solution, SNE is the symmetric Nash equilibrium and SWO is the symmetric social welfare optimum. Figure 2a shows how closely the average token investment paths track the respective symmetric solution path.

The second major column of Table 4 summarizes the results of the classification process on the 25-token experiments. Of the 80 subjects who took part in the 25-token experiments, 9 (11%) were classified as average revenue equalizers, 12 (15%) as Nash appropriators, and 8 (10%) as social welfare maximizers. Figure 2b reports the average per-period token investment path of the subjects classified as following one of the symmetric paths in the 25-token experiments. The token investment paths in Figure 2b are visibly more erratic than those in Figure 2a. This can be partially explained by the larger strategy set faced by subjects in the 25-token experiments.

The perceived differences between the subject classification results in 25-token and 10-token experiments led to questions on the effects the different experimental treatments have on subject behavior.

VI. Results: Treatment Effects on Subject Classification

These experiments had three distinct treatments: subject endowment, subject experience, and forecasting. Subject endowment level and subject experience level were treatments examined by Walker, Ostrom and Gardner at the aggregate level. They found that 25-token experiments tended to have higher market-2 token investment levels than 10-token experiments. They also found that experiments with experienced subjects tended to have higher market-2 token investment levels than experiments with inexperienced subjects.

The models assuming objective maximizing agents are mute on the effects of explicit forecasting or the effects of experience. Further, endowment levels should impact token investment levels only when the endowment constraint is binding. That is, the endowment treatment should not impact subject type, only token investment levels. If the 10-token endowment proved binding, then the 25-token experiments should exhibit higher aggregate token investment levels.

To test for significant treatment effects, the subject type results generated from the perfect-foresight best-response classification scheme (reported in Table 2) were used. This data set was used because it was measurable for all the experiments and represents an interpretation of objective maximizing agents. Proportions of subject type were pooled by experiment treatment types. Then the Z-test for the significance of difference between sample proportions was used on the target treatment, holding the other treatments constant.

Endowment Treatment. Table 5 reports the results of this procedure on the endowment treatment. Each cell in the table reports the Z-value of the test with the associated p-value in parentheses. As reported in the first row of Table 5, the 10-token experiments have a significantly {a = 0.05) lower proportion of average revenue equalizers than the 25-token experiments, across all treatment conditions. This is balanced, in the bottom row, by a significantly higher proportion of subjects following none of the best response paths. In fact, the 10-token experiments never report a higher proportion of subjects following a best-response path for any of the behavior types. The significant increase in average revenue equalizers in 25-token experiments over 10-token experiments is consistent with the observation of higher rent dissipation in 25-token experiments reported in Walker, Gardner and Ostrom (1990), but is inconsistent with the hypothesis that token endowment should not impact appropriator behavior.

Forecasting Treatment. Table 6 reports the results of the statistical tests examining the impact of forecasting on subject behavior. These tests show forecasting has no significant impact on subject behavior. A curious regularity does appear in the first and third column where forecasting experiments have lower proportions of Nash actors and average revenue equalizers in conjunction with higher proportions of subjects following no best-response path. These correspond with 10-token experiments and could be explained by subjects consistently mis-forecasting cohort token investment levels.

Experience Treatment. Table 7 reports the results of statistical tests examining the impact prior experience in the decision environment has on subject behavior. The tests show experience has no significant impact on subject behavior. There is not even a consistent pattern of signs on the test statistics across treatment types.

Thus, the only treatment with consistent and significant effects across experiment types was the endowment treatment. The other two treatments, forecasting and experience, had no significant effects on subject type.

VII. Concluding Comments

This study focused on the appropriation behavior of 216 subjects participating in 27 CPR experiments. It classified the subjects as to following one of three behavioral models. Overall, 79% of the appropriators followed a token investment path attributable to one of the models of subject behavior. With 74% of the appropriators following token investment paths attributable to privately rational behavior and 5% following token investment paths attributable to social welfare maximizing behavior. Given these results, it is reasonable to conclude that privately rational behavior is the dominant behavior mode. This includes subjects whose token investment paths follow one of their best response paths (65%) and those subjects whose token investment paths are consistent with myopically following one of the symmetric solutions (14%).

The observed heterogeneity of appropriator type helps to explain why none of the symmetric solutions are achieved in the experimental CPR literature. The high proportion of privately rational agents explains why the experimental CPR literature reports appropriation levels well above the social optimum.

APPENDIX A: Computerized Instructions

This is an experiment in decision making. The National Science Foundation has provided funds for conducting this experiment. The instructions are designed to inform you of the types of decisions you will be making and the results of those decisions. All profits you make during the experiment will be totalled and paid to you in privacy in cash at the end of the experiment. If you have any questions concerning the instructions feel free to raise your hand and one of the experiment monitors will assist you.

The experiment in which you are participating is comprised of a sequence of market periods. In each market period you will be asked to make a series of investment decisions. There are also 7 other persons in this experiment who will be making investment decisions.

Each period you will be allocated an endowment of 25 tokens.All other group members also have an endowment of 25 tokens. Total endowment for the group is 200 tokens.

You will decide each market period how you wish to invest your endowment between investment opportunities. The instructions which follow will describe the investment opportunities and the cash return from each opportunity.

Your return on investment of tokens in market 1 can be explained rather simply. Each token invested in market 1 yields you a return of one unit of commodity 1 and each unit of commodity 1 has a value of $ 0.05.

Thus for example:

1) If you invested 3 tokens in market 1 you would receive 3 units of commodity 1 valued at $ 0.15.

2) If you invested 6 tokens in market 1 you would receive 6 units of commodity 1 valued at $ 0.30.

3) If you invested 9 tokens in market 1 you would receive 9 units of commodity 1 valued at $ 0.45.

IN SUMMARY:

A) Each additional token invested in market 1 yields an additional cash return of $ 0.05.

B) On average you are receiving $ 0.05 per token invested in market 1.

The return on investment of tokens in Market 2 is a bit more complicated to explain. In Market 2 the return you receive on investments depends on the amount you invest as well as the amount all others in the group invest.

For example:

1) If the group as a whole invested 50 tokens in market 2 in a period in which you invested 6 tokens, you would receive 12% (6/50) of the units of commodity 2 earned by the group.

2) If the group as a whole invested 150 tokens in market 2 in a period in which you invested 12 tokens, you would receive 8% (12/150) of the units of commodity 2 earned by the group.

In summary, you receive a percentage of the total group return dependent upon what share of the total group investment you made.

INVESTMENT RETURN : MARKET 2

As in market 1, tokens invested in Market 2 yield units of commodity 2. Each unit of commodity 2 has a value of $ 0.01. However, the units of commodity 2 you receive for tokens invested in Market 2 is dependent upon how many tokens other members of your group invest in market 2.

If we define x as the total number of tokens invested in market 2 by all group members, we can calculate the number of units of commodity 2 produced as:

units of commodity 2 = ax-bx2
where: a=23 b=0.25

Examples:
1) if total tokens invested = 40 then total units of commodity 2 = 520

2) if total tokens invested = 140 then total units of commodity 2 = -1680.

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
20	360	$ 3.60	$ 0.18	$ 0.18
40	520	$ 5.20	$ 0.13	$ 0.08
60	480	$ 4.80	$ 0.08	$-0.02
80	240	$ 2.40	$ 0.03	$-0.12
100	-200	$ -2.00	$-0.02	$-0.22
120	-840	$ -8.40	$-0.07	$-0.32
140	-1680	$-16.80	$-0.12	$-0.42
160	-2720	$-27.20	$-0.17	$-0.52
180	-3960	$-39.60	$-0.22	$-0.62
200	-5400	$-54.00	$-0.27	$-0.72

The table shown above displays information on investments in market 2 at various levels of total group investment. A similar table will be at your disposal during the experiment. Lets talk about the meaning of the information given in the table.

The first column "Tokens Invested by the Group" gives example levels of total investment by the group in Market 2. These are examples to give you a sense of the payoff from Market 2 at various levels. Actual return from Market 2 will depend on exactly how many tokens your group invests in Market 2.

The second column labeled "Units of Commodity 2 Produced" gives the level of units of commodity 2 produced for each level of group investment. For example if 100 tokens were invested, there would be -200 units of commodity 2 produced.

The third column labeled "Total Group Return" displays the actual payoff to the entire group for a given level of group investment. For example, if the group invested 100 tokens, the total cash payoff to the group from investing in Market 2 would be $-2.00.

The fourth column, labeled "Average Return per Token," displays the cash value at any level of investment, but on a per token (average) basis. Thus, if the group invests 100 tokens, the average return per token in Market 2 is $-0.02.

The final column, labeled "Additional Return per Token Invested'", displays information on the extra value that is earned from additional tokens invested. Thus, when the level of group investment is at 100 tokens, the value of investing additional tokens into Market 2 is approximately $-0.22 per token.

1) the return you receive from tokens invested in market 2 depends on how many tokens you invest and how many tokens other group members invest in market 2.

2) you will not know how many tokens other group members have invested in group 2 when you make an investment decision in any one period.

3) your individual return from tokens invested in market 2 depends on what percentage of the total tokens invested in market 2 was made by you.

4) By pressing -LAB- during the experiment, you will be able to have the computer calculate the investment return for MARKET 2 for individual and group decisions levels chosen by you. Try this now by pressing the -LAB- key on your keyboard.

Yield from Market 2:

Before you make an investment decision during the experiment, you will have the choice of calling this option. By inserting an example level of group investment and individual investment chosen by you, you can have the computer compute the yield for Market 2 for the example you chose.

Choose an example for group investment: 70 ok
Choose an individual investment in Market 2: 10 ok

Units of commodity 2 produced = 385
Group return = $ 3.85
Individual return = $ 0.55

Lets take a practice trial to let you get a feel of what it means to actually invest your tokens. For illustrative purposes only, lets assume you decide to invest 12 of your tokens in market 1 and your remaining 13 tokens in market 2.

** For example purposes invest 12 tokens in market 1 and invest 13 tokens in market 2 **

Number of tokens you wish to invest in Market 1
Market 1 investment = 12 ok

Number of tokens you wish to invest in Market 2:
Market 2 investment = 13 ok

In this particular example we will assume that other members of the group invested a total of 88 tokens in the group. This makes total tokens invested in market 2 = 100. Further, this means that you invested 13% of the tokens in Market 2.

MARKET 1:
You invested 12 tokens.

This gives you a return of 12 units of product 1 valued at $ 0.05 per unit.
Total Cash Return = $ 0.60

MARKET 2:

You invested 13 tokens.
The total group investment was 100 tokens.

This gives the group a return of -200 units of product 2, valued at $ 0.01 per unit.
Total GROUP Cash Return = $-2.00.
Your Cash Return = 13% of the total = $-0.26.

This ends the explanation of investment opportunities. During the experiment you will be able to call up a summary of important details regarding the return from investments made in the alternative markets.

It is important you fully understand the opportunities for investment. If you have any questions, now is the time to ask. Just raise you hand.

Otherwise:
Press -NEXT- to proceed into the experiment
Press -BACK- to review
Press -DATA- for a summary of investment opportunities

ADDITIONAL INSTRUCTIONS

Please read these carefully

At the end of each investment period the computer will display a screen which shows the results of the recently completed period. After viewing the results you can move into the next decision period. Once you have entered the next decision period, you have many options. These include reviewing the history of decisions, entering a screen which allows you to calculate potential scenarios, and investing in the current period.

Before making your investment decision, you are to make a prediction on what you think the total investment of the others will be in Market-2. The total investment of the others will just be the total investment you expect in market-2 minus what you invest. You will then write this number down beside the appropriate period on the sheet provided for you.

An example: If you intend to invest 5 tokens in market-2 in period 1 and you expect the total investment in market-2 will be 40 tokens in period 1, then the amount you expect the others to invest in period 1 will be 40 - 5 = 35. You would then write 35 in the space beside period 1 on the worksheet provided.

At the end of the experiment an investment period will be randomly selected and the individual whose prediction of the total market-2 investment of others is closest to the actual for that period will receive an additional $3.00. This payment will be divided for ties.

<table>
<tr><th>Table 1</th><th colspan="8">Experimental Treatments</th></tr>
<tr><td></td><td colspan="8">Experiment Type</td></tr>
<tr><td></td><td colspan="4">10 Token</td><td colspan="4">25 Token</td></tr>
<tr><td>Market-2 Payoff Ftn</td><td colspan="4">$g(Y) = 23Y - .25(Y)^2$</td><td colspan="4">$g(Y) = 23Y - .25(Y)^2$</td></tr>
<tr><td>Number of Experiment</td><td colspan="4">17</td><td colspan="4">10</td></tr>
<tr><td>Number of Subjects</td><td colspan="4">136</td><td colspan="4">80</td></tr>
<tr><td></td><td colspan="2">No Forecasts</td><td colspan="2">Forecasts</td><td colspan="2">No Forecasts</td><td colspan="2">Forecasts</td></tr>
<tr><td>Number of Experiment</td><td colspan="2">8</td><td colspan="2">9</td><td colspan="2">3</td><td colspan="2">7</td></tr>
<tr><td>Number of Subjects</td><td colspan="2">64</td><td colspan="2">72</td><td colspan="2">24</td><td colspan="2">56</td></tr>
<tr><td></td><td>Exper</td><td>In Exper</td><td>Exper</td><td>In Exper</td><td>Exper</td><td>In Exper</td><td>Exper</td><td>In Exper</td></tr>
<tr><td>Number of Experiment</td><td>3</td><td>5</td><td>3</td><td>6</td><td>3</td><td>0</td><td>3</td><td>4</td></tr>
<tr><td>Periods in Experiment</td><td>30</td><td>20</td><td>30</td><td>20</td><td>20</td><td>20</td><td>20</td><td>20</td></tr>
<tr><td>Number of Subjects</td><td>24</td><td>40</td><td>24</td><td>48</td><td>24</td><td>0</td><td>24</td><td>32</td></tr>
</table>

Table 2: Number of Individuals Investing in a Way Not Significantly Different From One of their Best Response Functions Under the Perfect Foresight Assumption.

	Experiment Type							
	10-Token				25-token			
Average Revenue	16 (11.7%)				53 (66.3%)			
Nash Behavior	33 (24.3%)				24 (30.0%)			
Social Welfare	0 (0.0%)				2 (2.5%)			
None	87 (64.0%)				1 (1.2%)			
	No Forecasts		Forecasts		No Forecasts		Forecasts	
Average Revenue	10 (15.6%)		6 (8.3%)		15 (62.5%)		38 (67.9%)	
Nash Behavior	19 (29.7%)		14 (19.4%)		8 (33.3%)		16 (28.6%)	
Social Welfare	0 (0.0%)		0 (0.0%)		0 (0.0%)		2 (3.6%)	
None	35 (54.7%)		52 (72.2%)		1 (4.2%)		0 (0.0%)	
	Exper	In Exper	Exper	In Exper	Exper	In Exper	Exper	In Exper
Average Revenue	6 25.0%	4 10.0%	2 8.3%	4 8.3%	15 62.5%	-	16 66.7%	22 68.8%
Nash Behavior	8 33.3%	11 27.5%	6 25.0%	8 16.7%	8 33.3%	-	7 29.2%	9 28.1%
Social Welfare	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	-	1 4.2%	1 3.1%
None	10 41.7%	25 62.5%	16 66.7%	36 75.0%	1 4.2%	-	0 0.0%	0 0.0%

Table 3: Number of Individuals Investing in a Way Not Significantly Different From One of their Best Response Functions Using Actual Forecast Data

	Experiment Type			
	10-Token		25-token	
Average Revenue	8 (11.1%)		28 (50.0%)	
Nash Behavior	21 (29.2%)		7 (12.5%)	
Social Welfare	0 (0.0%)		2 (3.6%)	
None	43 (59.7%)		19 (33.9%)	
	In-Experienced	Experienced	In-Experienced	Experienced
Average Revenue	4 (8.3%)	4 (16.7%)	17 (53.1%)	11 (45.8%)
Nash Behavior	17 (35.4%)	4 (16.7%)	6 (18.8%)	1 (4.2%)
Social Welfare	0 (0.0%)	0 (0.0%)	1 (3.1%)	1 (4.2%)
None	27 (56.3%)	16 (66.7%)	8 (25.0%)	11 (45.8%)

Table 4: Number of Individuals Investing in a Way Not Significantly Different From One of the Symmetric Solutions.

	Experiment Type							
	10-Token				25-token			
Average Revenue	24 (17.6%)				9 (11.2%)			
Nash Behavior	34 (25.0%)				12 (15.0%)			
Social Welfare	9 (6.6%)				8 (10.0%)			
None	69 (50.7%)				51 (63.8%)			
	No Forecasts		Forecasts		No Forecasts		Forecasts	
Average Revenue	11 (17.2%)		13 (18.1%)		2 (8.3%)		7 (12.5%)	
Nash Behavior	17 (26.6%)		17 (23.6%)		3 (12.5%)		9 (16.1%)	
Social Welfare	4 (6.2%)		5 (6.9%)		1 (4.2%)		7 (12.5%)	
None	32 (50.0%)		37 (51.4%)		18 (75.0%)		33 (58.9%)	
	Exper	In Exper	Exper	In Exper	Exper	In Exper	Exper	In Exper
Average Revenue	5 20.8%	6 15.0%	6 25.0%	7 14.6%	2 8.3%	-	2 8.3%	5 15.6%
Nash Behavior	3 12.5%	14 35.0%	4 16.7%	13 27.1%	3 12.5%	-	4 16.7%	5 15.6%
Social Welfare	0 0.0%	4 10.0%	1 4.2%	4 8.3%	1 4.2%	-	3 12.5%	4 12.5%
None	16 66.7%	16 40.0%	13 54.2%	24 50.0%	18 75.0%	-	15 62.5%	18 56.2%

Table 5: Impact of Endowment on Subject Best Response Behavior Z-test for Significance of Difference Between Two Independent Sample Proportions: 10-Token to 25-Token Experiments Under the Assumption of Perfect Foresight.			
	Experiment Type		
	Experienced Forecasting	Inexperience Forecasting	Experienced NonForecast
Average Revenue Equalizing	-4.44 (0.00)	-5.71 (0.00)	-2.65 (0.01)
Nash Behavior	-0.31 (0.76)	-1.18 (0.24)	0.00 (1.00)
Social Welfare Maximizing	-0.97 (0.33)	-1.18 (0.24)	N/A
Neither	4.92 (0.00)	6.61 (0.00)	3.13 (0.00)

Table 6: Impact of Forecasting on Subject Best Response Behavior Z-test for Significance of Difference Between Two Independent Sample Proportions: Forecasting to Non-Forecasting Experiments Under the Assumption of Perfect Foresight.			
	Experiment Type		
	10-Token Experienced	25-Token Experienced	10-Token Inexperience
Average Revenue Equalizing	-1.58 (0.11)	0.29 (0.85)	-0.33 (0.74)
Nash Behavior	-0.61 (0.54)	-0.30 (0.76)	-1.25 (0.21)
Social Welfare Maximizing	N/A	0.97 (0.33)	N/A
Neither	1.74 (0.08)	N/A	1.22 (0.22)

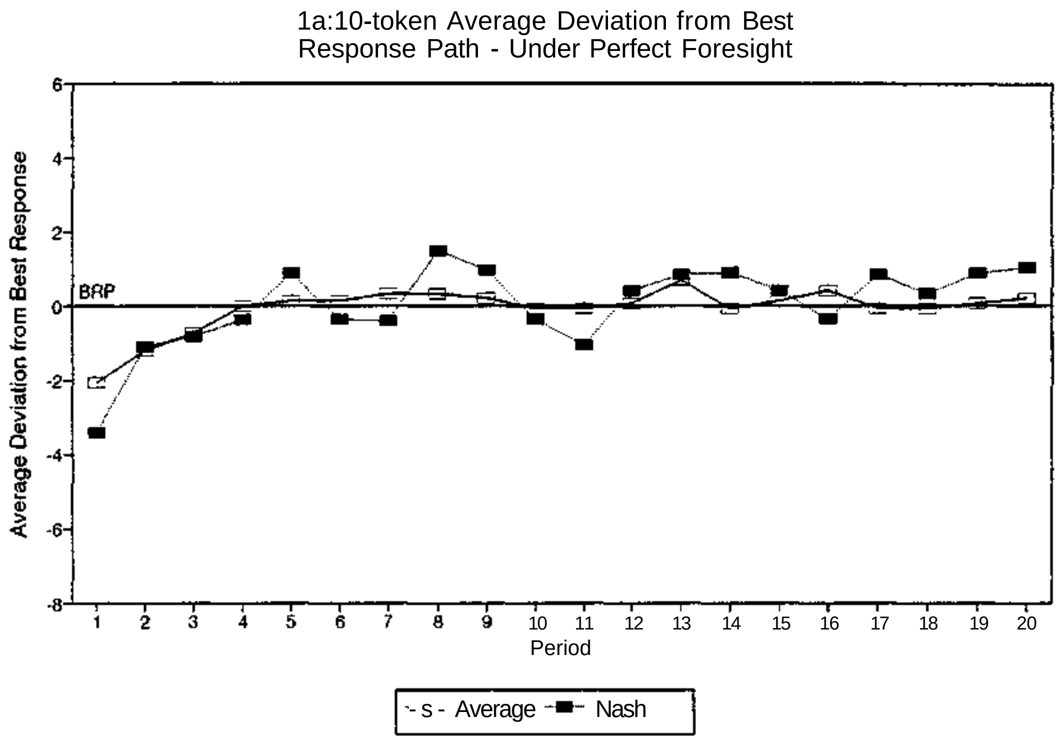
N/A denotes sample proportions equal at zero so the z-test is not defined.

Table 7: Impact of Experience on Subject Best Response Behavior Z-test for Significance of Difference Between Two Independent Sample Proportions: Experienced to Inexperienced Experiments Under the Assumption of Perfect Foresight.

	Experiment Type		
	10-Token Forecasting	25-Token Forecasting	10-Token NonForecast
Average Revenue Equalizing	0.00 (1.00)	-0.16 (0.87)	1.60 (0.11)
Nash Behavior	0.81 (0.42)	0.08 (0.94)	0.42 (0.67)
Social Welfare Maximizing	N/A	0.20 (0.84)	N/A
Neither	-0.71 (0.48)	N/A	-1.63 (0.10)

N/A denotes sample proportions equal at zero so the z-test is not defined.

Figure 1


1a:10-token Average Deviation from Best Response Path - Under Perfect Foresight
Average Deviation from Best Response
BRP
Period
- s - Average -■- Nash

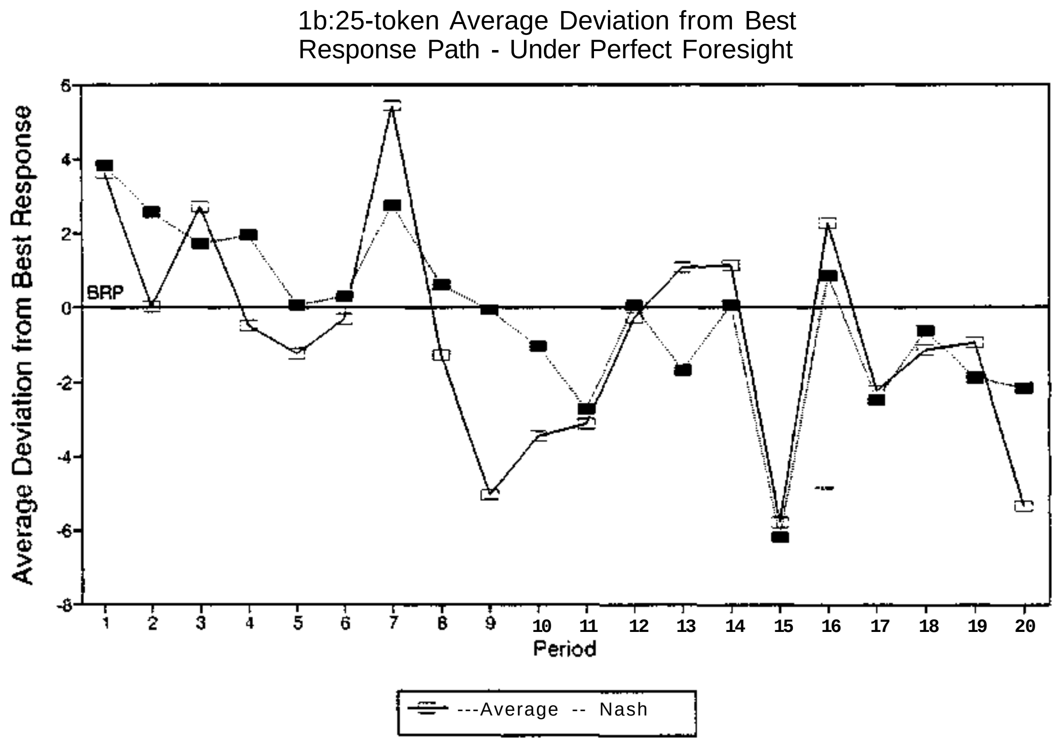
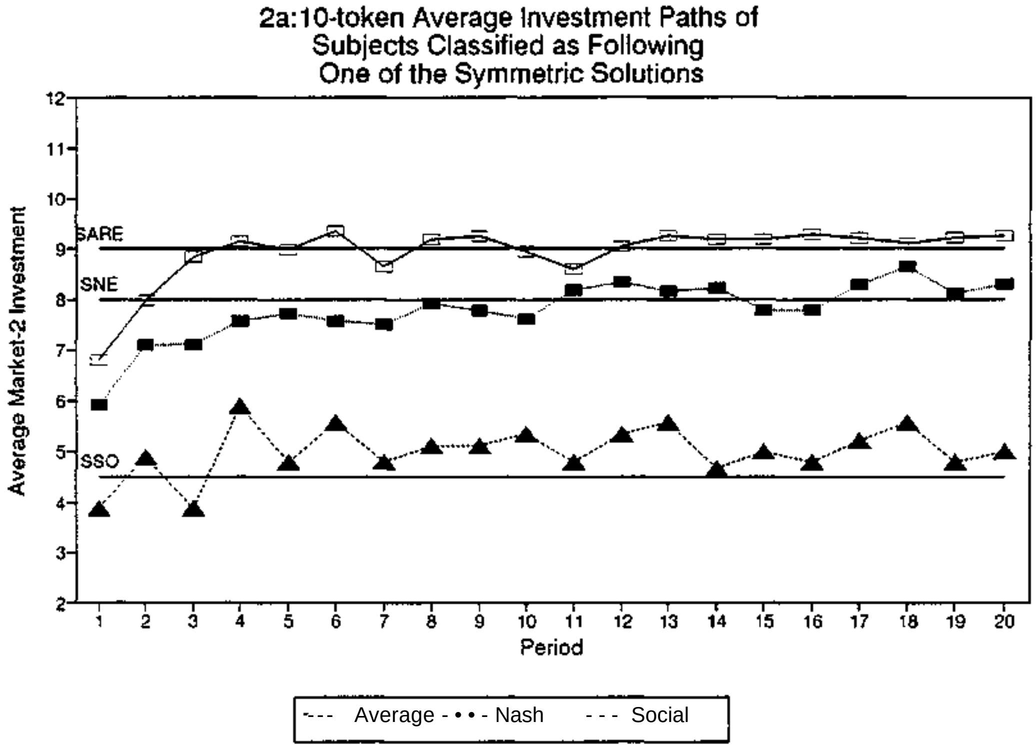
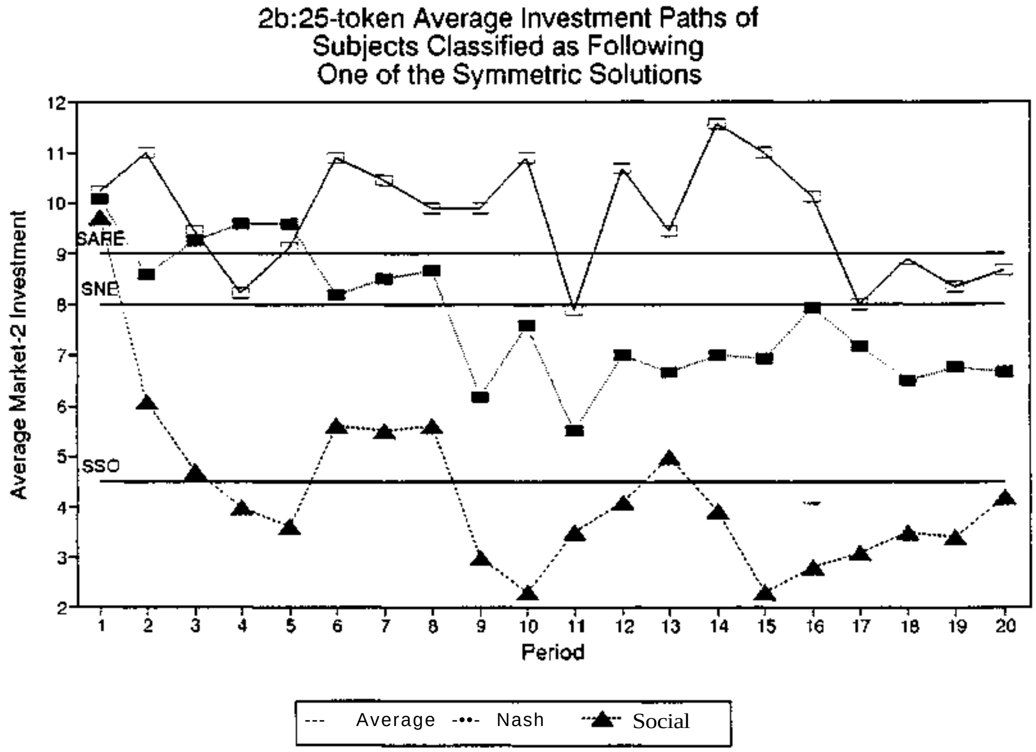

1b:25-token Average Deviation from Best Response Path - Under Perfect Foresight
Average Deviation from Best Response
BRP
Period
---Average -- Nash

Figure 2


2a:10-token Average Investment Paths of
Subjects Classified as Following
One of the Symmetric Solutions
Average Market-2 Investment
Period
SARE
SNE
SSO
Average
Nash
Social


2b:25-token Average Investment Paths of
Subjects Classified as Following
One of the Symmetric Solutions
Average Market-2 Investment
Period
SARE
SNE
SSO
Average
Nash
Social

CHAPTER 4

FORECASTING BEHAVIOR IN EXPERIMENTAL COMMON POOL RESOURCE APPROPRIATION AND PUBLIC GOOD PROVISION ENVIRONMENTS

I. Introduction

It is not unusual for a decision maker to be in an environment where outcomes are contingent upon the decision maker's strategy and an event which reveals itself simultaneously with the decision maker's strategy choice. Thus, a decision maker selects a strategy given some a priori belief as to the nature of the event. John Muth (1961) proposed these forecasts held certain characteristics. In particular, Muth proposed the subjective probability distribution used by a rational decision maker to make an informed prediction of a future event is the same as the objective probability distribution about the realization of the event itself. This implies that a rational decision maker's prediction is an efficient and an unbiased estimate of the event. A competing view of forecasting behavior explicitly models the forecasting process. In the adaptive model of forecasting behavior, a current forecast of an event is the old forecast updated after the realization of the prior event, taking into account forecast error.

Many empirical investigations of the Muthian Rational Expectations (RE) forecasts have focused on price forecasting. The investigations include survey-based studies on aggregate price indices (Thies [1986], Bryan and Gavin [1986], DeLeeuw and Mckelvey [1984] and Gramlich [1983]) . These studies ask participants to forecast aggregate prices over time. They find little evidence supporting RE forecasts. There have also been experimental studies of price forecasting where subjects forecast prices in experimental markets (Williams [1987], Garner [1982]). Again, the data are not supportive of RE price forecasts.

They do, however, show evidence consistent with adaptive forecasts.

Though the Williams (1987) market experiments, where subjects forecast mean prices, were designed to establish a "(non-trivial) sufficient environmental condition" for RE forecasting, I feel there are environmental factors which complicated the forecasting task and need to be addressed. In this type of market environment there is a necessary position asymmetry between subjects; some are buyers and some sellers. In addition, there are individual induced valuation asymmetries that encourage trade by all of the subjects. Given these asymmetries, the focus of individual buyers and sellers is their intra-period price path (in attempts to extract a larger share of available buyer/seller surplus) and not the "mean price." Thus, forecasting the mean price is ancillary to the task of trading. To address the asymmetry issue a forecasting environment with a unique symmetric solution and a single position is needed. In addition, the forecast target needs to be a primary concern of the participants.

In common pool resource (CPR) appropriation, discussed in Chapter 3, forecasts of cohort appropriation levels are necessary for best response appropriation. The same is true for the public good provision problem discussed in Chapter 2.

Walker, Gardner and Ostrom (1990) investigated a series of repeated play symmetric CPR appropriation experiments. Groups of eight subjects made appropriation decisions in each of twenty to thirty repetitions of the CPR environment. The unique, symmetric Nash equilibrium was never played. An investigation into individual appropriator behavior in these CPR environments found a limited number of subjects appropriate in a way consistent with Nash best response functions (Dudley 1992). A similar lack of convergence to Nash equilibrium play was observed in the Isaac and Walker (1992) public good experiments. One explanation for non-Nash behavior is subjects' inability to form accurate forecasts of cohort appropriation or provision levels; resulting in biased forecasts.

In this study, appropriator forecasting behavior in an experimental CPR setting with a unique symmetric Nash equilibrium and provider forecasting behavior in an experimental public good setting are examined[1]. The next section gives a brief overview of the experimental environments in which subject forecasts were made. The results are then analyzed in section III and concluding comments are made in section IV.

II. Experimental Environment

As, to date, there is little empirical support for the rational expectations hypothesis. The experimental environments investigated here, have design characteristics which should not impede RE forecasting behavior.

The CPR experiments were a supergame consisting of twenty or thirty repetitions of a one-shot CPR constituent game described in Chapter 3, Walker Gardner and Ostrom (1990) and Dudley (1992) . Each subgame had a unique symmetric Nash equilibrium. The only subgame perfect Nash equilibrium to the supergame consisted of consecutive play of the subgame Nash equilibrium. Thus, as in Williams (1987), the supergame was an operational approximation of a steady state environment. In this environment the subjects were asked to forecast cohort investment in the CPR. The public good experiments were a supergame consisting of 10 repetitions of a one-shot internal Nash public good constituent game as described in Chapter 2 and Isaac and Walker (1992). In this environment the subjects were asked to forecast cohort investment toward the public good.

All the experiments were run on the NovaNET computer network. The subjects were volunteers from principles of microeconomics courses at Indiana University. Their earnings were the sum of: 1) the return from

---

[1] These experiments are explained in greater detail in chapters 2 and 3.

tokens (generic production units) invested into two experimental "markets[2]," 2) $3.00 for showing up on time to the experiment and, 3) $3.00 for the subject whose forecast error was the smallest in a period randomly selected at the conclusion of the experiment[3]. The CPR experiments had eight subjects and the public good experiments had 4 subjects; each with symmetric payoff and strategy sets.

A total of 2816 forecasts were collected from the subjects in 16 CPR experiments. In 10 of the CPR experiments the subjects were inexperienced; they had never participated in a CPR experiment before. In 6 experiments the subjects were experienced volunteers recruited from the 10 inexperienced experiments. The experienced experiments always had subjects from more than one of the inexperienced experiments. This design allows for comparison between forecasts made by novices and individuals who had experienced the environment and then returned to participate again. Thus, forecasting can be examined as a time series through a single experiment as well as comparing forecasts in experienced runs to inexperienced runs. The experiments are also differentiated by token endowment. In nine of the experiments, the subjects had a smaller per-period strategy set of 10 tokens. In the remaining 7 experiments subjects had a larger per-period strategy set of 25 tokens.

A total of 240 forecasts were collected from the 24 subjects in the 6 public good forecasting experiments. All of the subjects had participated in a previous non-forecasting trainer experiment.

---

[2]In the CPR experiment the choice is between Market-1 (a private productive process) and in Market-2 (a CPR). In the public good experiments the choice is between the Private Exchange (the private process) and the Group Exchange (the public good).

[3]The reasons for this payoff mechanism are explained in Chapters 2 and 3. There was no explicit payment made for forecasts in the 10-token CPR experiments for reasons explained in Chapter 3.

III. **The** Experimental Results

In both the CPR and public good environments, theory indicates that income maximizing subjects will seek to maximize their joint return from the two "markets." As shown in chapters 2 and 3, this yields best response criteria that are functions of cohort market-2 or group exchange investment. Thus, subjects have an incentive to forecast cohort investment levels ($\tilde{Y}^T_{-i}$). An appropriator's forecast error, in period t, is the difference between observed cohort investment and the forecast, or

$$\text{FORECAST ERROR} = {}^t Y^T_{-i} - {}^t \tilde{Y}^T_{-i}.$$

Summary of Aggregate Behavior. In these experiments, as is seen in other CPR and internal Nash public good experiments, the one-shot Nash equilibrium was never achieved. In the CPR experiments the average aggregate market-2 investment levels were near those predicted by the Nash equilibrium[4]. In addition, as described in Chapter 3, 52% of the subjects in these experiments followed investment paths not significantly different from a best-response path. In the public good experiments, as reported in chapter 2, 45% of the subjects had group exchange investment paths consistent with one of their best response paths.

Figure 1 displays a frequency histogram of forecast errors pooled across all subjects in all the CPR experiments. Figure 2 is a frequency histogram of forecast errors pooled across all subjects in all of the public good experiments. The tendency for forecast errors to concentrate closely around zero implies effort on the part of the subjects to minimize forecast error.

The distribution of the forecast errors in Figure 1 is skewed to the right, implying a bias to under estimate cohort market-2 investments; as evidenced by mean = 1.97 > median = 1 > mode = -2.

---

[4]For more in depth analysis of these points see Walker, Gardner, Ostrom (1990).

Cohort forecast error also falls across a broad range from -51 tokens to 58 tokens with a standard deviation of 12.00 tokens. In addition, the mean forecast error is significantly different from zero at any reasonable significance level with

= 8.66.

The distribution of the public good experiment forecast errors in Figure 2 is skewed to the left, implying a bias to over estimate cohort group exchange investments; as evidenced by mean = -5.75 < median = -3 < mode = 2. Cohort forecast error also falls across a broad range from -148 tokens to 91 tokens with a standard deviation of 33.76 tokens. In addition, the mean forecast error is significantly different from zero at any reasonable significance level with t = -2.64.

Analysis of Individual Behavior. Though forecasting behavior has implications on group outcomes, forecasting is an individual level behavior. Thus, tests for the RE hypothesis and adaptive forecasting must be done on the individual level.

The Rational Expectations Hypothesis. A test of the RE hypothesis comes from Muth's (1961) assertion that "Information is scarce, and the economic system generally does not waste it." Thus, information contained in an individual's previous forecasting error is updated into current forecasts. There should be no residual information from a past forecast error in a current forecast error. This restriction on forecasts implies forecast errors should not be serially correlated. With the regression equation

$$({}_tY^T_{-i} - {}^tY^T_{-i}) = \beta_0 + \beta_1({}_{t-1}Y^T_{-i} - {}^{t-1}Y^T_{-i}) + \mu_t$$

If the RE hypothesis is valid then the restriction Ho: $\beta_1 = 0$ will be accepted.

Table 1 reports the results of the fixed effects panel regressions. Subjects were pooled by experiment type. First order serial correlation is rejected in all poolings except the 10 token inexperienced CPR and Nash-48 public good experiments; lending limited support to the RE hypothesis. Homogeneity between subjects within poolings is rejected for each experiment type.

The lack of homogeneity across subjects implies potential bias in the estimates of β. To compensate for the potential bias individual level regressions were run. As reported in Table 2, at a significance level (X = 0.05, serial correlation of forecast errors can be rejected for 87.5% of both the CPR and the public good subjects; reversing the fixed effects results for the 10 token inexperienced and Nash-48 experiments. Table 2 also reports findings at the 10% and 50% significance levels indicating the robustness of failing to reject Ho. These results strongly support the efficient use of information implied by the RE hypothesis.

The RE hypothesis, also implies that an appropriator's forecast of cohort investment levels is an unbiased estimate of the realized cohort investment levels or

$$Y^{T}_{-i} = \hat{Y}^{T}_{-i} + v.$$

Forecasts of cohort investment levels ($\hat{Y}^{T}_{-i}$) predict the actual cohort investment levels (Y^{T}_{-i}) up to a random error term with a zero mean (v). This specification can be tested using the time-series regression equation

$$^{t}Y^{T}_{-i} = \beta_{o} + \beta_{1}\,^{t}Y^{T}_{-i} + {}^{t}\mu$$

with the null hypothesis Ho: $(\beta_0, \beta_1) = (0, 1)$.

Table 3 reports the results of the fixed effects panel regressions. The Hypothesis $\beta_1 = 1$ is easily rejected for all experiment types. The homogeneity across subjects within a pooling is also rejected.

Because of the lack of homogeneity, the restricted regression model (βo = 0 , βi = 1) was run for each subject. As shown in Table 4, with a = 0.05, only 18.8% of the CPR subjects and 33.3% of the public good subjects have unbiased forecasts. These results do not support unbiased forecasts as pervasive in the subject pool.

The RE hypothesis suggests both efficient information use and unbiased forecasts. Those subjects meeting both criteria show evidence of making RE forecasts. The pooled results support efficient use of information but do not support unbiased forecasts. From the individual level tests, only 17.8% of the subjects have forecasts consistent with both criteria. This does not support RE forecasts as descriptive of individual level forecasting. And, biased forecasts is consistent with the observed skewed distributions of pooled forecast errors reported in Figures 1 and 2.

Adaptive Forecasts. Adaptive forecasting behavior implies current forecasts are updates of prior forecasts from lagged forecast errors. This type of forecasting, coupled with uncorrelated forecast errors, implies a current forecast of cohort market-2 token investment (${}^{t}Y^{T}$) is derived from a function that weights lagged one period cohort group exchange or market-2 investment forecasts (${}^{t-1}Y^{T}_{-i}$) together with lagged one period forecast error (${}^{t-1}Y^{T}_{-i} - {}^{t-1}Y^{T}_{-i}$). Yielding the adaptive specification of

$$ {}^{t}Y^{T} = {}^{t-1}Y^{T}_{-i} + \beta_1 ({}^{t-1}Y^{T}_{-i} - {}^{t-1}Y^{T}_{-i}) . $$

This yields the regression equation

$$ {}^{t}Y^{T} - {}^{t-1}Y^{T}_{-i} = \beta_o + \beta_1 ({}^{t-1}Y^{T}_{-i} - {}^{t-1}Y^{T}_{-i}) + {}^{t}\mu, $$

with the null hypothesis Ho: $\beta_o = 0$ and $0 < \beta_1 < 1$.

Table 5 reports the results from the fixed effects panel regressions. The hypothesis $\beta_1 > 0$ and $\beta_1 < 1$ is supported for all experiment types, with β_1 ranging from 0.42 to 0.71. Homogeneity across subjects within experiment type is also accepted. In addition, $\beta_0 = 0$ is accepted for 72.7% of the CPR subjects and 62.5% of the public good subjects.

The individual level regressions were run for consistency with the RE forecasting tests. As shown in Table 6, β_1 is significantly less than one and significantly greater than zero (a = 0.05) for 75.8% of the CPR subjects and 33.3% of the public good subjects. This is strong evidence that adaptive learning is a useful model for describing the subjects' forecasting behavior in the CPR experiments.

Experience Effects on Forecasting Behavior. Folk wisdom, "practice makes perfect," implies that experienced subject's forecasts should more closely follow one of the behavioral models. Figure 3 shows the distribution of forecast error for experienced and inexperienced subjects in the CPR experiments. The distribution of forecast errors for the inexperienced subjects is more dispersed and has a larger mean than the distribution for the experienced subjects. The Kolmogorov-Smirnov test indicates experience has a significant effect on the accuracy of forecasting behavior at **a** = 0.025 that is consistent with the proposition that experience improves forecasting accuracy.

Table 7 examines the effects of experience on forecasting behavior. Table 7 reports the Z-values and p-values for the Z-test of significance of difference of sample proportions between subjects in experienced and inexperienced runs of the CPR experiments holding their token endowment constant. A positive Z-value indicates the proportion associated with experienced subjects exceeds that of the inexperienced subjects.

The effects attributable to subject experience level are mixed. A significantly larger proportion of 25 token experienced subjects have efficient forecasts. This effect is not exhibited with the 10 token experiments. A significantly larger proportion of 10 token experienced subjects have unbiased forecasts; but this is not seen in the 25 token experiments. Though the results are mixed, the general trend for positive Z-values in the top two rows of Table 7 is consistent with the increased forecasting accuracy due to experience reported in Figure 3. They, also, weakly support a tendency of experienced subjects toward RE forecasts.

IV. Concluding Comments

For forecasts to be considered Muthian rational expectations forecasts they need to meet two criteria.

1) The efficient use of scarce information, implying no serial correlation in forecast errors.

2) A parity between the subjective and the objective probability distributions about the forecast target, implying rational expectations forecasts are unbiased estimates of event realizations.

Both the fixed effects panels and the individual level regressions strongly reject serial correlated forecast errors, strongly supporting efficient information usage. The panel tests reject unbiased forecasts and this result is strengthened with only 18.8% of the CPR subjects and 33.3% of the public good subjects evidencing unbiased forecasts in the individual level tests. These results show the rational expectations hypothesis as a poor description of forecast behavior in these experimental environments.

There is strong evidence from the panel tests supporting subjects use adaptive learning in their forecasts. This result is supported by the individual level tests of the CPR subjects. There is, at best, weak support by the individual level tests of the public good subjects. As with other forecasting studies in other environments, adaptive forecasts are more descriptive of actual forecasts than Muthian rational expectations forecasts. The dominance of adaptive forecasting over RE forecasts is mitigated by tests on the effects of experience in the CPR experiments. These tests show modest evidence that experience increases RE forecasting.

There is an interesting behavioral difference in forecasting between the CPR and public good experiments. Subjects tend to under estimate cohort appropriation in the CPR experiments and tend to over estimate cohort provision in the public good experiments. This behavior, in both cases, tends to push subjects away from socially optimal behavior; due to over optimistic beliefs of cohort investment.

Table 1 Tests for Serial Correlation: Ho: $\beta_1 = 0$. (Fixed Effects Model)			
	β	t-value (p-value)	Homogeneity F-test (p-value)
10 Token Inexperienced	0.0996	3.019 (0.002)	3 .67 (0.00)
10 Token Experienced	-0.00657	-0.185 (0.853)	8.53 (0.00)
2 5 Token Inexperienced	-0.0716	-1.799 (0.072)	3.76 (0.00)
25 Token Experienced	-0.0785	-1.682 (0.093)	6.13 (0.00)
Nash-2 00	0.0579	0.541 (0.588)	1.29 (0.24)
Nash-48	0.312	2 .972 (0.003)	12 .47 (0.00)

Table 2 Tests for Serial Correlation: Ho: $fi_x = 0$. Proportion of Subjects Failed to Reject Ho (OLS t-test)			
	Significance Level		
	0.05	0.10	0.50
10 Token	0.889	0.806	0.431
25 Token	0.857	0.821	0.589
Pooled	0.875	0.813	0.500
Nash-200	0.833	0.833	0.333
Nash-48	0.917	0.917	0.417
Pooled	0.875	0.875	0.375

Table 3 Tests for Unbiasedness: Ho: $\beta_x = 1$. (Fixed Effects Model)			
	β	t-value (p-value)	Homogeneity F-test (p-value)
10 Token Inexperienced	0.241	31.574 (0.000)	3.30 (0.00)
10 Token Experienced	-0.0130	-33.875 (0.000)	14.83 (0.00)
25 Token Inexperienced	-0.0279	-24.711 (0.000)	3.21 (0.00)
25 Token Experienced	-0.0495	-19.180 (0.000)	6.41 (0.00)
Nash-200	0.666	3.486 (0.001)	5.77 (0.00)
Nash-48	0.211	10.045 (0.000)	13.64 (0.00)

Table 4 Tests for Unbiasedness: Ho: {($\beta_0 = 0$, ($\beta_1 = 1$) Proportion of Subjects Failed to Reject Ho. (Restricted Least Squares F-test)			
	Significance Level		
	0.05	0.10	0.50
10 Token	0.292	0.236	0.097
25 Token	0.054	0.036	0.000
Pooled	0.188	0.148	0.055
Nash-200	0.583	0.417	0.000
Nash-48	0.167	0.167	0.083
Pooled	0.333	0.292	0.042

Table 5 Tests for Adaptive Forecasts Ho: $\beta_o = 0$ and $0 < B < 1$. (Fixed Effects Model)

	β_1	t-value 0i > 0 0i < 1	p-value p-value	Proportion of Subjects $\beta_o = 0$
10 Token Inexperienced	0.556	23.999 -19.181	0.000 0.000	0.729
10 Token Experienced	0.592	24.127 -16.574	0.000 0.000	0.750
2 5 Token Inexperienced	0.523	20.789 -18.995	0.000 0.000	0.688
2 5 Token Experienced	0.421	14.551 -20.039	0.000 0.000	0.750
Nash-200	0.710	11.520 -4.713	0.000 0.000	0.833
Nash-48	0.571	7.579 -5.711	0.000 0.000	0.417

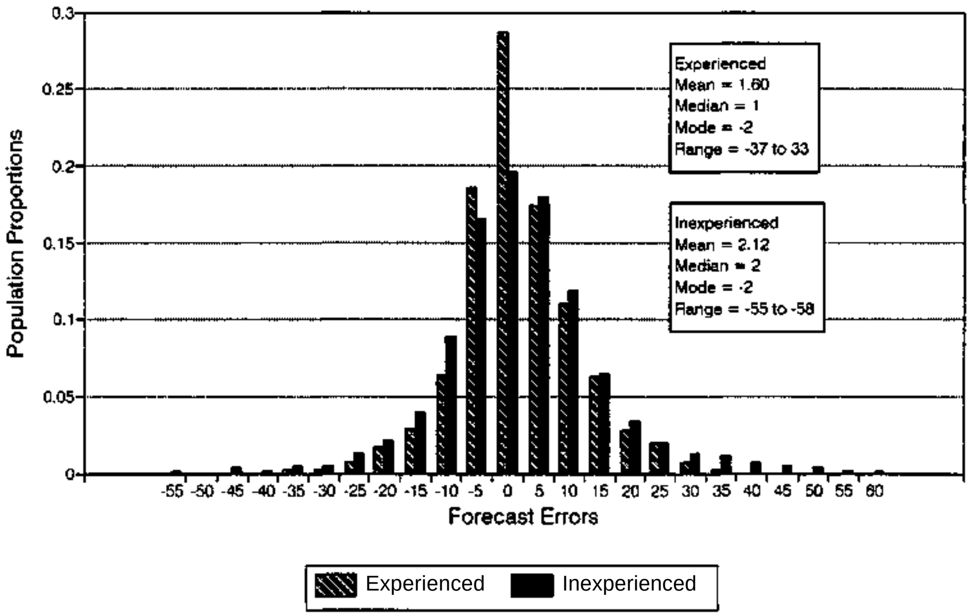
Table 6 Test for Adaptive Forecasts. Proportion of Subjects Meeting the Criteria at Significance Level a = 0.05 (OLS t-tests)

	$0 < \beta_1 < 1$	$\beta o = 0$	00 = 0 $0 < \beta_1 < 1$
10 Token	0.792	0.778	0.611
2 5 Token	0.714	0.865	0.571
Pooled	0.758	0.789	0.594
Nash-200	0.333	1.000	0.333
Nash-48	0.333	0.917	0.250
Pooled	0.333	0.958	0.292

Table 7 Tests for Significance of Experience Level Treatment Effects on Sample Proportions Holding Token Endowment Constant. (Data from Individual Level Tests)

	Significance of Difference Z-value (p-value)	
	10 Token	25 Token
Non-Serially Correlated Errors	-0.30 (0.764)	1.99 (0.047)
Unbiased Forecasts	2.75 (0.006)	0.42 (0.674)
Adaptive Forecasts	-2.22 (0.026)	0.94 (0.272)

Figure 3: Experienced V. Inexperienced
Distribution of Forecast Errors



CHAPTER 5

CONCLUDING COMMENTS

This study is the synthesis of three interrelated parts. The first two parts investigated individual level behavior in two different social dilemma environments. They investigated individual level provision behavior in an experimental internal-Nash voluntary contribution public good environment and individual level appropriation behavior in an experimental limited-access common pool resource environment. Of primary interest was whether individuals interacted with purely privately rational motives, ignoring the social costs imposed by their decisions, or whether they interacted with socially rational (social welfare maximizing) motives, internalizing the social costs imposed by their decisions. The third part investigated subject forecasting behavior in those two environments. Here the focus was on whether Muthian rational expectations or adaptive forecasting were descriptive of individual forecasting behavior.

Over all, 75% of the subjects participating in the two experimental environments exhibited provision or appropriation behavior consistent with either privately or socially rational motives. The majority of the subjects, 66% exhibited privately rational behavior and a minority, 9% exhibited socially rational behavior. This result implies that private rationality is the dominant behavioral motive in these two social dilemma environments.

When the results are disaggregated by experiment type an interesting asymmetry appears. A larger proportion of the public good experiment subjects exhibit behavior consistent with socially rational motives[1]. In addition a larger proportion of CPR experiment subjects

---

[1]The test for significance of difference between sample proportions yields a Z-value of $Z = 4.14$ and a p-value of $p = 0.00$.

exhibit behavior consistent with privately rational motives[2]. In the public good experiments, 43% of the subjects exhibit behavior consistent with private rationality and 21% of the subjects exhibit behavior consistent with social rationality. In comparison, 74% of the subjects in the CPR experiments exhibit behavior consistent with private rationality and 5% exhibit behavior consistent with social rationality.[3]

The difference in observed behavior between the two experimental environments is surprising because of the structural similarity between the two environments. Both environments consist of subjects investing tokens into two "markets"; a "private market" yielding a fixed marginal return per token and a "group market". The "group market" consisted of an aggregate production function, that had a negative quadratic form in both experiment types, and a sharing rule that apportions the aggregate production between the subjects. In the public good experiments the sharing rule equally divided the aggregate output between all subjects. In the CPR experiments the aggregate output was distributed to subjects in proportion to their token investment in the "group market." The public good and CPR experiments can also be differentiated by duration (10 periods in the public good experiments and 20 to 30 periods in the CPR experiments) and group size (4 subjects in the public good experiments and 8 subjects in the CPR experiments. Finally, the two decision environments were framed differently. The instructions and the

[2]The test for significance of difference between sample proportions yields a Z-value of $Z = 4.91$ and a p-value of $p = 0.00$.

[3]A study by Isaac and Walker (1988) suggests that marginal per-capita return (MPCR) and not group size induces behavioral change in public good experiments. In the public good experiments in this study, the MPCR was group investment dependent and not fixed. The MPCR is not a well defined concept in the CPR experiments because a subject's share of aggregate output is not fixed. Thus, the MPCR's influence is not measurable in these experiments.

decision environment of the public good experiments were more group oriented.[4]

The impact of the sharing rule on participant behavior needs to be investigated more closely. Experiments holding group size, duration and aggregate production function constant, varying only the sharing rule need to be run. If the result that an equal share rule results in greater socially rational behavior in social dilemma environments holds under a more controlled test, it implies the counter intuitive argument that institutionally transforming CPRs into public goods (collectivizing CPRs) may have social welfare enhancing effects.

The final section of this study examined forecasting behavior in the CPR and public good environments. Over all, adaptive forecasting was more descriptive of subject forecasts than Muthian rational expectations (RE). In the CPR experiments, there was some evidence suggesting experienced subjects' forecasts had increased RE characteristics. In addition, tests on forecast errors suggested CPR subjects tended to under estimate cohort appropriation and public good subjects tended to over estimate cohort provision. In a sense, it seems that in these two environments, subjects believe their cohorts are bigger "suckers" than they really are. In both cases, these beliefs tend to push rational (objective maximizing) subjects away from the social optimum; regardless of whether they are socially rational or privately rational. In the public good experiments, over estimated cohort group exchange investments induce lower private or social best responses. In the CPR experiments, under estimated cohort market-2 investments induce higher best responses.

This forecasting bias can drive outcomes beyond a subject's target outcome. Periodically the impact due to forecast bias will result in an outcome which causes subjects to significantly reevaluate their current

[4]To see these differences read the computerized instructions in the appendices of chapter 2 and 3.

investment strategy. This adjustment will be evidenced by a pulse in the outcome towards the social optimum. This pulsing behavior is consistent across the CPR experiments. This dynamic may be one of the roots of the pulsing aggregate investment behavior in these CPR experiments.

References

Bell, Frederick, "Technological Externalities and Common Property-Resources: An Empirical Study of the U.S. Lobster Industry", Journal of Political Economy, v.80 p.148-158 (1972)

Bresnahan, "Duopoly Models With Consistent Conjectures", American Economic Review, v.71 p.934-945 (1981)

Bryan, Michael F. and William T. Gavin, "Models of Inflation Expectations Formation: A comparison of Household and Economisr Forecasts" Journal of Money, Credit, and Banking v.18 p.539-544 (1986)

Clark, "Restricted Access to Common-Property Fishery Resources: A Game Theoretic Analysis" in Dynamic Optimization and Mathematical Economics p.117-132 Plenum, New York (1980)

Cornes, Richard and Todd Sandier, The Theory of Externalities, Public Goods, and Club Goods Cambridge University Press, London/New York (1986)

Dawes, Robin, "Social Dilemmas" Annual Review of Psychology v.31 p.169-193 (1980)

De Leeuw, Frank and Michael J. McKelvey "Price Expectations of Business Firms: Bias in the Short and Long Run" The American Economic Review v.74 p.99-110 (1984)

Dudley, Dean, "Individual Choice in a Common Pool Resource Environment: An Experimental Analysis" Presented at the Midwest Economics Association meetings, Chicago, March (1992)

Dwyer, Gerald, Arlington Williams and Raymond Battalio, "Tests of Rational Expectations in a Stark Setting" forthcoming Economic Journal (1993)

Gardner, Roy and Elinor Ostrom, "Rules and Games" Public Choice (1990)

Gardner, Roy, Elinor Ostrom and James Walker, "The Nature of Common-Pool Resource Problems" Rationality and Society v.2 p.335-358 (1990)

Garner, Alan, "Experimental Evidence on the Rationality of Intuitive Forecasts" Research in Experimental Economics v.2, edited by Vernon Smith, Greenwich: J.A.I. Press, p.155-173 (1982)

Gordon, H. Scott, "The Economic Theory of a Common Property Resource: The Fishery" Journal of Political Economy v.62 p.124-142 (1954)

Gramlich, Edward M. "Models of Inflation Expectations Formation: A Comparison of Household and Economist Forecasts" Journal of Money, Credit, and Banking v.15 p.155-173 (1983)

Hogg, Robert and Allen Craig, Introduction to Mathematical Statistics 4th Edition, Macmillan Publishing Co., Inc., New York/London (1978)

Isaac, Mark, James Walker and Susan Thomas, "Divergent Evidence on Free Riding: An Experimental Examination of Possible Explanations" Public Choice v.43 p.113-149 (1984)

Isaac, Mark, Kenneth McCue and Charles Plott, "Public Goods Provision in an Experimental Environment" Journal of Public Economics v.26 p.51-74 (1985)

Isaac, Mark and James Walker, "Group Size Effects in Public Goods Provision: The Voluntary Contribution Mechanism" Quarterly Journal of Economics February p.179-199 (1988)

Isaac, Mark and James Walker, "Communication and Free-Riding Behavior: The Voluntary Contribution Mechanism" Economic Inquiry v.26 p.585-608 (1988b)

Isaac, Mark and James Walker "Nash as an Organizing Principle in the Voluntary Contribution of Public Goods" Mimeo, Indiana University, October 7 (1992)

Kalai, Ehud and Ehud Lehrer, "Rational Learning Leads to Nash Equilibrium" Discussion Paper #895, The Center for Mathematical Studies in Economics and Management, Northwestern University, March (1990)

Kalai, Ehud and Ehud Lehrer, "Subjective Equilibrium in Repeated Games" Discussion Paper #981, The Center for Mathematical Studies in Economics and Management, Northwestern University, February (1992)

Kim, Oliver and Mark Walker, "The Free Rider Problem: Experimental Evidence" Public Choice v.43 p.3-24 (1984)

Lehmann, L. and H. D'Abera Nonparametries: Statistical Methods Based on Ranks Holden-Day, Inc. Oakland (1975)

Lovell, Micheal C. "Tests of the Rational Expectations Hypothesis" The American Economic Review v.76 p.110-124 (1986)

Mason, Charles F., Todd Sandier and Richard Cornes, "Expectations, the Commons, and Optimal Group Size" Journal of Environmental Economics and Management v.15 p.99-110 (1988)

Messick, David and Carol McClelland, "Social Traps and Temporal Traps" Personality and Social Psychology Bulletin v.9 p.105-110 (1983)

Muth, John, "Rational Expectations and the Theory of Price Movements" Econometrica v.29 p.315-335 (1961)

Ostrom, Elinor, Governing the Commons: The Evolution of Institutions for Collective Action Cambridge University Press, London/New York (1990)

Ostrom, Elinor, Roy Gardner and James Walker, "Covenants With and Without a Sword: Self Governance is Possible" American Political Science Review v.86 p.1-14 (1992)

Perry, Martin, "Oligopoly and Consistent Conjectural Variations" Bell Journal of Economics v.13 p.197-205 (1982)

Samuelson, Paul A. "The Pure Theory of Public Expenditure" Review of Economics and Statistics v.36 p.387-389 (1954)

Samuelson, Paul A. "A Diagrammatic Exposition of a Theory of Public Expenditure" Review of Economics and Statistics v.37 p.350-356 (1955)

Schmalensee, Richard "An Experimental Study of Expectation Formation" Econometrica v.44 p.17-41 (1976)

Smith, Vernon, Gerry Suchanek and Arlington Williams, "Bubbles, Crashes and Endogenous Expectations in Experimental Spot Asset Markets" Econometrica v.56 p.1119-1151 (1988)

Thies, Clifford F. "Business Price Expectations 1947 - 83" Journal of Money, Credit , and Banking v.18 p.336-354 (1986)

Walker, James, Roy Gardner and Elinor Ostrom, "Rent Dissipation in a Limited-Access Common-Pool Resource: Experimental Evidence" Journal of Environmental Economics and Management v.19 p.203-211 (1990)

Williams, Arlington, "The Formation of Price Forecasts in Experimental Markets" The Journal of Money, Credit, and Banking v.19 p.1-17 (1987)

CURRICULUM VITAE

DEAN DAVID DUDLEY

HOME ADDRESS
299 Y Street
New Windsor, NY 12253
(914) 567-6069

Department of Social Science
United States Military Academy
West Point, NY 10996
(914) 938-2898

FIELDS OF SPECIALIZATION
Political Economy
Public Finance
Industrial Organization

PERSONAL
Birthdate: 28 may 1958
Marital Status: Married, five children

DISSERTATION

ESSAYS ON INDIVIDUAL BEHAVIOR IN SOCIAL DILEMMA ENVIRONMENTS: AN EXPERIMENTAL ANALYSIS

In this study a series of computer assisted experimental Common Pool Resource and Voluntary Contribution Public Goods environments are used to collect data on and investigate the individual choices made by subjects. Given a separation between privately rational and socially optimal strategies, this thesis studies how the competing theories of human behavior hold against the choices made by individuals in these environments. It also studies how one-period-ahead individual forecasting behavior converges to rational expectations forecasts. Information on individuals' choices and forecasting behavior should lead to more effective policy formation with respect to social dilemma environments.

Chairman: Professor James Walker, Acting Director of the Workshop in Political Theory And Policy Analysis, Indiana University, Bloomington, In

EDUCATION
Ph.D. Candidate, Economics, Indiana University, Bloomington, In
B.A., Economics, Eastern Washington University, Cheney, Wa, 1986

TEACHING EXPERIENCE
Assistant Professor, Dept. of Social Science, United States Military Academy, West Point, NY. August 1993 to Present.

Associate instructor, Dept. of Economics, Indiana University, Bloomington, In. August 1990 to July 1992 (five semesters). Course Taught: E201 Introduction to Microeconomics.

PAPER PRESENTATIONS
"Forecasting Behavior in Experimental Common Pool Resource Appropriation and Public Good Provision Environments" Seminar, Dept. of Soc. Sci. USMA, West Point, NY, August 1993.

"Individual Choice in a Common Pool Resource Environment: An Experimental Analysis" Presented at the Mid-West Economics Association meetings. Chicago, II, March 1992.

"Individual Behavior in an Experimental CPR Environment," paper presented at the Mini-Conference of the Workshop in Political Theory and Policy Analysis, Indiana University, Bloomington, In., May 1989.

"Exciudability: A Composite Symptom of the Institution of Exchange and the Nature of the Resource," paper presented at the Mini-Conference *of* the Workshop in Political Theory and Policy Analvsis. Indiana University, Bloomington, In., Dec 1988.

RESEARCH POSITIONS

Visiting Research Associate to the Workshop in Political Theory and Policy Analysis, Indiana University, Bloomington In, Aug. 1992 to Aug. 1993.

Research Assistant to the Workshop in Political Theory and Policy Analysis, Common Property Resource project, May 1991 to August 1991.

Research Assistant to Professor David Wildasen, Project on Differential Net Social Security Benefits with Mobile Labor in the EEC, August 1990.

Research Assistant to the Workshop in Political Theory and Policy Analysis, Head of experimental computer lab for Committee Voting project, August 1989 to August 1990.

Research Assistant to the Workshop in Political Theory and Policy Analysis, Common Property Resource project, August 1988 to August 1989.

PROFESSIONAL MEMBERSHIPS

American Economic Association (student member)
MidWest Economics Association

REFERENCES

Assistant Professor **Steven Hackett**
Professor Roy **Gardner**
Professor **James Walker,**
Acting Director of the Workshop in
Political Theory and Policy Analysis.
Professor **Arlington Williams**

Department of Economics
Ballantine Hall 901
Indiana University
Bloomington, In 47405
(812) 855-1021

Distinguished Professor **Elinor Ostrom,**
Co-director of the Workshop in
Political Theory and Policy Analysis,
Arthur F. Bentley Professor In Political Science.

Workshop in Political Theory and Policy
Indiana University
513 North Park
Bloomington, In 47405
(812) 855-0441