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PRIVATE INCENTIVES IN SOCIAL DILEMMAS: THE EFFECTS OF INCOMPLETE INFORMATION AND ALTRUISM

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by

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Abstract

This paper analyzes the provision of discrete public goods when individuals have altruistic preferences which others do not precisely know. The problem is formulated and solved as a Bayesian game. In contrast to standard social psychological approaches, based on such natural language terms as greed, fear, and trust, the Bayesian approach provides a rigorous mathematical treatment of social participation. This theory is shown to make strong testable predictions that can integrate data collected across a wide variety of natural and experimental settings. The altruism model is shown to be supported by existing experimental data on binary voluntary contribution games.

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Private Incentives in Social Dilemmas

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I. Introduction

Participation or contribution often generates collective benefits that exceed collective costs. On the other hand, an individual's own benefit from contributing may well depend upon other individuals' contribution choices. One particular version of this problem specifies a threshold level of contribution required for the generation of these collective benefits, and can be thought of as the provision of a discrete public good. This type of problem has been termed a "social dilemma" (Dawes, 1980). Key questions in the analysis of social dilemmas include: (1) How can incentives to make voluntary contributions be structured to achieve "better" allocations of public goods? (2) Is there a model which can be used to accurately predict or explain behavior under a broad variety of incentive structures without requiring a separate assumption to explain behavior under each variation in incentives? These two questions, one normative and the other positive, remain largely unanswered.

The development of theoretical models[1] that address these questions has been stimulated in recent years by the rapid accumulation of a large body of data from laboratory experiments on the voluntary provision of public goods.[2] While these experiments may differ dramatically from one another in their incentive structures, they all attempt to induce preferences by providing monetary payoffs. What we argue here is that key aspects of preference are

not controlled for in these experiments despite the strong monetary inducements.[3] We offer a solution to this problem by formally modelling the effects of imperfectly controlled preferences in social dilemma experiments.

The aspect of uncontrolled preferences we focus upon involves utility derived directly from acts of social cooperation or contribution, the utility of altruism or social duty. The concept of altruism may be given an operational definition in a variety of ways. Among economists [e.g., Roberts (1984)], altruism is often specified in terms of an individual utility function that depends upon the consumption levels or utility functions of other individuals. In our public goods context, we define altruism in a different but related way. *Altruism* is defined here as an additive component of utility that depends solely on how much the individual contributes.

We wish to emphasize that the interesting results of our model are not a trivial consequence of the fact that individuals may "like to contribute." To "explain" the data by saying that people contribute only because it is fun to do so would be uninteresting. What matters in a social dilemma is the uncertainty each individual has about how many others in the group will contribute. We choose to model this uncertainty as deriving from privately known altruistic preferences. This is a matter of convenience as much as anything else. Many alternative specifications are conceivable all of which involve introducing some privately known components to complement the experimentally induced monetary rewards. These alternatives include risk preferences and general non-monetary utility payoffs as a function of how many other individuals are contributing, which could be interpreted as either "income effects" or "conditional altruism". Some of these alternatives are discussed in more detail at the end of the paper. One compelling reason for choosing to model altruism as the unknown component is that there is widespread belief, supported by more than casual experimental evidence, that individuals in these experiments behave altruistically, at least in the sense we intend it: that the "real" cost to participants of making a contribution is significantly less than the direct monetary cost imposed by the rules of the experiment.

We thus present a model of social dilemmas as games in which all monetary incentives are common knowledge but in which altruism is private information. All individuals are the same a priori, in the sense that the private non-monetary components of preferences are assumed to be drawn from a distribution that is identical for all individuals (and common knowledge). The resulting game of incomplete information is analyzed in terms of Bayesian Nash equilibrium (Harsanyi, 1967-68). The equilibrium strategies turn out to be very simple rules of thumb: contribute if one's altruism exceeds some threshold level, otherwise do not contribute. This equilibrium analysis produces several simple testable hypotheses, which we confront with data from experiments conducted by others in recent published research. A central prediction of the model is that contribution rates should be inversely related to the equilibrium cutpoint. Using data from various social dilemma experiments, we test whether this inverse relationship holds. Moreover, this inverse relationship is predicted to hold across *different* payoff structures and so we are able to utilize data produced from a variety of apparently different experimental environments.

We feel that testing the empirical implications of the Bayesian equilibrium model is particularly important in light of the considerable experimental evidence that has been accumulated recently which indicates that

individual behavior under uncertainty is not always consistent with the maximization of expected utility and which indicates that individuals do not always make statistical inferences consistent with Bayes' rule[5]. In contrast to these negative findings, the experimental results reported here indicate that our Bayesian equilibrium model fits *aggregate* behavior reasonably well, at least in the social dilemma experiments examined here.

2. A Two Person Example

We begin with a simple example to illustrate the basic approach. Two individuals, A and B, are independently asked by an "organizer" to contribute \$c < \$1.00 for a non-exclusive public good which costs exactly \$c to produce. If at least one of them contributes, the public good will be provided. If both happen to contribute, the "organizer" pockets one of the contributions, but still produces the good. If no one contributes, the good is not produced. The public good has a "money value" of \$1 to both A and B. If we assume that each of their utility functions is linear in "money value" then the payoff matrix[4] for the game is given in Figure 1.

		Player B: Contribute	Player B: Don't Contribute
Player A	Contribute	1-c (B) / 1-c (A)	1 (B) / 1-c (A)
	Don't Contribute	1-c (B) / 1 (A)	0 (B) / 0 (A)

Figure 1. Payoff Matrix

This game has 2 pure strategy equilibria (exactly one of the players contributes) and a mixed strategy equilibrium in which each player contributes with probability 1-c.

In the formulation in which the players each have an additional "altruism" component to their utility function, d_A, d_B, the payoff matrix is given in Figure 2.

		Player B	
		Contribute	Don't Contribute
Player 1	Contribute	$1+d_B-c$ / $1+d_A-c$	1 / $1+d_A-c$
	Don't Contribute	$1+d_B-c$ / 1	0 / 0

Figure 2. Payoff Matrix with Altruistic Preferences.

Since, we will be assuming that d_i is private information to i, the natural candidate for a non-cooperative solution concept is Bayesian equilibrium, and we have to specify priors each player has about the other player's d value. We will assume that each player has a well-defined prior about the other player's d value, that this prior is the same for both players and that it can be represented by the distribution function, F(d).[6]

A symmetric equilibrium to this game is characterized as a strategy or decision rule expressed in terms of a "cutpoint" d^*, such that individual i contributes if $d_i > d^*$, defects if $d_i < d^*$, and takes either action if $d_i = d^*$. Equilibrium results if, when both players use d^*, neither player can achieve a higher expected utility by using an alternative strategy.

Observe that, if $d_i > c$ then player i has a dominant strategy to

contribute and, if $d_i < c-1$ then player i has a dominant strategy not to contribute. Throughout the paper, we refer to such individuals as <u>benevolents</u> and <u>malevolents</u>, respectively.[7]

The behavior of individuals without dominant strategies will depend upon their expectations about the behavior of others as embodied in their knowledge of F(d) and the monetary incentive structure specified by the parameter c. Define the equilibrium probability that a player contributes as:

$$q^* = 1 - F(d^*) \tag{1}$$

The equilibrium hypothesis requires that the expected utility of contribution must equal the expected utility of defecting, given that the other player uses the decision rule d^* and therefore contributes with probability q^*. This generates a second equation, given below:

$$1 - c + d^* = q^* \tag{2}$$

An equilibria (q^*, d^*) is any pair which simultaneously solves (1) and (2). For this special example, a unique equilibrium always exists as long as F is continuous and $F(c-1) < 1$. In general, existence will not be a problem, but uniqueness can be problematic, as is discussed later.

3. Symmetric Binary Contribution Games

In this section, we extend the preceeding example of a two person game to the analysis of N player contribution games where all players are symmetric with respect to monetary payoffs. Each player i has two alternative actions denoted $s_i \epsilon (0,1)$ where $s_i = 1$ denotes contribution and $s_i = 0$ denotes non-contribution. As above, we assume that players share a common prior, denoted by F(d).

In all the experimental public goods environments we analyze, the monetary payoff an individual receives depends only on the number of other individuals who contribute and on s_i. Letting m_i denote the number of individuals other than i who choose contribution, we use the notation $v(m_i, s_i)$ to indicate monetary payoffs. Finally, dropping the i subscript for convenience, we use π_j to denote the probability player i assigns to the event $m_i = j$.

For our simple model of altruism in binary contribution games, the total utility to a contributor can be written as $v(m_i, 1) + d_i$, and the total utility to non-contributors as $v(m_i, 0)$. Altruism enters additively, and individuals are risk neutral with respect to monetary payments.

At the cutpoint d^*, the expected utility of contribution must equal the expected utility of non-contribution. We obtain:

$$\sum_{j=0}^{N-1} \pi_j v(j,1) + d^* = \sum_{j=0}^{N-1} \pi_j v(j,0)$$

or

$$d^* = \sum_{j=0}^{N-1} \pi_j [v(j,0) - v(j,1)] \qquad (4)$$

The probabilities π can all be expressed in terms of q, the probability that a randomly selected individual will contribute. In equilibrium, $q = q^*$ as given by equation (1). Values of q^* and d^* that simultaneously solve equations (1) and (4) represent a symmetric Bayesian Nash equilib to the game.[8]

Games of particular interest are the specifications of the $v(\cdot)$ functions chosen by Van de Kragt et. al. (1986) and Simmons et. al. (1983) in conducting a large number of one shot voluntary contributions experiments. Most of their games are threshold games, where w is the threshold. If there are sufficient

contributions to reach the threshold, a public good is provided.[9] The cost of contribution is c, $0 < c < 1$. The relevant specifications are included in Table 1.

Table 1 About Here

The first game described in the table is a variant of Chicken (Luce and Raiffa, 1957). Being "chicken" is equivalent to contributing, as one would prefer to receive the monetary benefit of 1 without having to incur the cost of contribution, c. In addition, contributions past the threshold are wasted. Two adapted versions of this game, called No Fear and No Greed were designed by Simmons et. al. (1983) to eliminate some of the disincentives to contribution that exist in Chicken.

In the No Fear game, contributions are refunded if the threshold is not met. As an example of No Fear, some corporate tender offers (see Grossman and Hart, 1980) have a payoff structure similar to No Fear. The tenderer offers to buy all shares offered at a stated price provided some fraction of the shares is offered. This price is <u>below</u> the market value the stock would enjoy if the tender succeeds but is <u>above</u> the market value if the offer fails. Each shareholder would prefer to hold his shares, if he or she could be sure that enough other stockholders would tender. There are numerous related illustrations from the corporate world which involve incentive structures similar to these "No Fear" tender offers.[10]

The No Greed game in fact removes any incentive to hold out to avoid the cost of contributing. All players are forced into contributing and receive only 1-c whenever at least w individuals contribute. But, in contrast to No

Fear, one can still be "stuck" with the contribution cost of c if the threshold isn't met.

There are, of course, many other possibilities. One, which we call Control, removes both the "greed" and the "fear" disincentives. There are both refunds and compulsory contributions. If fewer than w individuals contribute, contributions are refunded. If at least w individuals contribute, the rest of the individuals are all forced to contribute. Majority voting on a head tax is a particular institutional mechanism which is approximated by this game.

The "Poison" game shown in Table 1 is another example of a natural setting that can be analyzed in our framework. Poison differs from No Fear only in that the tender offer is unconditional. Consequently, contributors always receive 1-c even if the threshold is not met. Our labelling this variant Poison owes its inspiration to Time's[11] account of the takeover struggle between T. Boone Pickens and the management of Unocal. The quantity 1-c represents the $54 per share Pickens was offering for Unocal stock. The quantity 1 corresponds to the $72 per share Unocal's "poison pill" plan would bestow on remaining stockholders were Pickens to succeed in acquiring a majority interest. The quantity 0 represents the relatively low value the stock would have (less than $54) if Pickens' takeover attempt failed.

The remaining two games in the table represent two actual experiments where non-contribution was a dominant strategy in terms of the monetary payoffs. In Dominant, a player receives a payoff only if *w* others contribute. The player's own decision is never critical to the player's receiving a "public" payoff. A player's contribution only affects whether others receive their "public" payoffs. Hence, only benevolent individuals will contribute.

In Incremental, every contribution of c bestows a value of b on each of the *other* players. Again, only benevolent individuals have an incentive to contribute. For these experiments, equilibrium is trivially characterized by $d^* = c$.

We next apply equation (4) to each of the other games for which experimental results exist and for Control. The resulting equilibrium conditions are:

$$d^* = c - \binom{N-1}{w-1} q^{*w-1} (1-q^*)^{N-w} \qquad \text{(5a) (Chicken)}$$

$$d^* = c \sum_{k=w-1}^{N-1} \binom{N-1}{k} q^{*k} (1-q^*)^{N-1-k} - \binom{N-1}{w-1} q^{*w-1} (1-q^*)^{N-w} \qquad \text{(5b) (No Fear)}$$

$$d^* = c \sum_{k=0}^{w-1} \binom{N-1}{k} q^{*k} (1-q^*)^{N-1-k} - \binom{N-1}{w-1} q^{*w-1} (1-q^*)^{N-w} \qquad \text{(5c) (No Greed)}$$

$$d^* = (c-1) \binom{N-1}{w-1} q^{*w-1} (1-q^*)^{N-w} \qquad \text{(5d) (Control)}$$

Note that in the Control variant the cut point must be negative. Individuals with positive d will always contribute. Failure to observe 100 per cent contribution in the Control situation would indicate, from the perspective of this model, that the subject pool included malevolent individuals.

4. Comparative Statics

In this section, we present some general comparative statics for the equilibria to the binary contribution games represented by equations (5a-5d).

There are two basic types of comparisons. In the first, we hold constant c, w, N, and $F(\cdot)$ and compare the equilibria that result when the incentive structure is varied. In the second, we look within incentive structures and ask how contribution rates and the cutpoint change as either c, w, N, or $F(\cdot)$ is varied while all other features of the game are held constant.

Changing the Incentive Structure

Which incentive structure leads to greater participation? A partial answer to this question is available from two facts. (1) The right hand side of equation (1) is decreasing in d^*. (2) For fixed q^*, the right hand side of (5a) is greater than the right hand side of either (5b) or (5c). In turn, the right hand side of either (5b) or (5c) is greater than that of (5d). These two facts imply the following:

Proposition.

Fix c, N, w and $F(\cdot)$.

(1) There exists at least one stable equilibrium to Chicken.

(2) For each stable equilibrium in Chicken, there exist stable equilibria to No Fear, No Greed, and Control, respectively such that the equilibrium levels of contribution are less in Chicken than in either No Greed or No Fear, which are in turn less than in Control.

The above points are illustrated in Figure 3, where we have graphed equations (5) for one of the Simmons et. al. (1983) experimental conditions, namely $w=3$, $N=7$, $c = 0.5$. This figure shows how the Chicken curve lies above the others while No Fear and No Greed both lie above Control. Observe,

however, that No Greed and No Fear are ambiguously ordered. The same pattern is repeated in Figure 4, which represents the same conditions but with $w=5$. For the function 1-F(d) in Figure 4, each incentive structure has a unique equilibrium. The equilibria satisfy the partial order represented by the proposition. But for the function 1-G(d) in Figure 4, both Chicken and No Greed have three equilibria, the outer two being stable. In this case one of the stable equilibria for No Greed has a lower participation probability than one of the stable equilibria to Chicken.

Changing the Game Parameters

We examine the following comparative statics:

1. The effect of increasing the cost of contributing (c) on the equilibrium contribution rate ($q^* = 1-F(d^*)$), and the cutoff point (d^*).
2. The effect of increasing the degree of altruism of the players [a rightward shift of the distribution function $F(\cdot)$] on q^* and d^*. We index distributions by a parameter α such that, for all d, $\partial F(d)/\partial\alpha \leq 0$.
3. The effect of increasing the number of individuals in the game (N) on q^* and d^*.
4. The effects of increasing the threshold level (w) on q^* and d^*.

Table 2 about here

We analyze these for each incentive structure. The details are worked out in the Appendix. A summary is contained in Table 2. It may be useful to refer to Figures 3 and 4 in order to visualize the intuition for the different results. Most of our comparative static results for stable equilibria are intuitive and straightforward. The result that contribution rates are increasing in altruism and decreasing in the cost of contribution for all mechanisms considered is fairly obvious. The interpretation of the effects of changing w and N are a bit more complicated. The proper intuition is provided by considering Chicken. An increase in w changes the proportion of contributions required for provision of the public good. This induces a rightward shift in the equilibrium curve, reflecting the fact that a larger proportion of the population must contribute in order for the public good to be provided. If the equilibrium expected number of contributors excluding one individual was less than w-1 $\left(\text{i.e., } q^* < \frac{w-1}{N-1}\right)$ then this change reduces the probability that any individual would be pivotal since the probability an individual is pivotal is maximized at $q = \frac{w-1}{N-1} > q^*$. If this individual had been a marginal contributor ($d^i = d^* + \epsilon$) he will no longer contribute. This effectively increases d^*. The process continues until a new equilibrium point is reached. The stability condition guarantees that this adjustment process converges locally. If q^* is greater than $\frac{w-1}{N-1}$, a similar argument shows that the probability that someone will be a marginal contributor increases in w.

An increase in N has an opposite effect to an increase in w -- that is, it decreases the proportion of contributors required for the provision of the public good. This induces a leftward shift in the equilibrium curve, resulting in comparative statics exactly opposite to the effect of w.

The effect of increasing α on the cutpoint is similar to that of increasing N. A rightward shift in the distribution curve has the same effect as a leftward shift in the equilibrium curve. However, even when an increase in α causes the cutpoint to increase, the increase never completely offsets the distribution shift, so the contribution rate always increases.

A Special Case: w=1

Comparative statics analysis is straightforward in the special case (w=1) where only a single contributor is required. This case has also been explored in a different context by Samuelson (1984). Chicken and No Fear are identical in this case as are No Greed and Control. The expected utility conditions become:

$$d^* = c - (1-q^*)^{N-1} \qquad \text{(5a')}$$
(Chicken, No Fear)

$$d^* = (c-1)(1-q^*)^{N-1} \qquad \text{(5c')}$$
(No Greed, Control)

These equations show that d^* is monotonically increasing in q^* when w=1. Consquently, the symmetric equilibrium is always unique and the comparative statics are those given by the first column in Table 2. Thus, the w=1 case would provide a setting for some strong experimental tests of the theory. However, the available experimental data all have w>1.

5. Analysis of Experimental Data

We now proceed to apply our analysis to the experimental data. The data we use and a detailed description of experimental procedures are presented in Simmons, et. al. (1983), Dawes, et. al. (1985) and Van de Kragt et al. (1986). They followed standard procedures, which included testing for subject comprehension of the task and understanding of the monetary payoff rules. Such testing was important since naive subjects were used.

The following two relevant initial observations can be made by inspecting Figures 3 and 4:

1. In Figure 4, the curve labelled 1-F(d) represents one possible

distribution of d. For this distribution, No Greed would have the highest level of contribution and No Fear would have a level slightly greater than Chicken, as observed in the experiments. In contrast, the curve labelled 1-G(d) produces multiple equilibria for Chicken and No Greed and a single, stable equilibrium for No Fear. Moreover, of the two stable equilibria for No Greed, one would have a participation rate barely greater than that of No Fear while the other would have a participation rate near zero. Thus, in contrast to the assertion by Simmons, et. al. (1983) that removing greed has more effect on stimulating contribution than does removing fear in general, we would argue that contribution will depend upon both the subjective distribution of altruism held by the subjects and the incentive structure. Even making a relatively small change in a single parameter (compare Figures 3 and 4) can make a large difference in contribution rates for a fixed distribution.

2. The No Greed and No Fear curves intersect at d = 0. As a result, the experimental observation of substantially greater contribution rates for No Greed than No Fear indicates that the No Greed equilibrium must occur for a negative value of d^*. This is suggestive of some degree of malevolent behavior in the experimental population.

For the remaining analysis, we assume that when multiple equilibria exist, the same one will occur in every experimental replication. While this is a strong assumption, it might be motivated by efficiency arguments or by appealing to cultural norms leading to a Schelling-point type of solution to the tacit coordination problem. Unlike, say, the $\binom{N}{w}$ permutations of a w-contributor equilibrium in a game of complete information, one out of several d^* equilibria values may well be prominent. And, in the many

situations where there is a unique equilibrium, the assumption is irrelevant.

Given this assumption together with the assumptions made in Section 3, we can make a stronger prediction about the ordering of experimental results than is possible under the complete information model:

<u>*The Inverse Monotonicity Hypothesis (IMH)*</u>. *If* q^* *is measured experimentally and equation (4) is then solved for* d^*, *conditional on the experimental value of* N, w, c, *and the game variant, then* q^* *and* d^* *will have a strictly inverse monotonic relationship.*

Note that IMH is an extremely useful hypothesis for empirical purposes, since it can be tested by combining data from a very wide range of experimental situations. The key testing problem, of course, is that q^* cannot be measured directly. But there is an obvious natural estimator of q^* in experimental settings[12]. This is simply the proportion of observed contributors in a set of experiments employing the same game variant.

As a test of IMH consider the data summarized in Table 3. These represent ten experimental environments. The parameters w and N and the incentive structures vary across these environments. Each experimental subject participated in only one game. We consider only games with no pre- play communication among participants. Participants learn their payoff but are never told either how many individuals contributed (except implicitly in Incremental) or which specific individuals contributed.

The data from Table 3 are displayed graphically in Figure 5 and illustrate a clear negative relationship between q* and d* as predicted by IMH. There are a variety of statistical tests available to formally quantify the degree to which the data in Table 3 support IMH. Since IMH is an ordinal hypothesis, ordinal mesures of association are appropriate. One such measure is Spearman's rank order correlation which for our data is simply the correlation between the rank orders of q^* and d^* in Table 3. The Spearman correlation is -0.88 (N=10). A one-tailed t-test rejects the hypothesis that the correlation is 0 at a significance level better than 0.001. Alternative ordinal measures of association (Hildebrand et al., 1977) also produce highly significant values. Finally, using a cardinal measure, the raw correlation between d^* and q^* is -0.85, which is also significantly less than 0 at better than the 0.001 level.

Since our hypothesis seems to be well supported, visual inspection of Figure 5 readily provides some rough estimates of the degree of altruism in the experimental population. Many individuals appear to have a relatively high sense of altruism. The median individual $[F(d^*) = 0.5]$ seems to have been willing to give up about \$3.50 of a \$5.00 endowment for the value of serving as a contributor. However, there is substantial variance in altruism. Indeed, the fact that there is less than unanimous contribution for the three experiments with d^* near zero suggests there are significant numbers of malevolent individuals.

In addition to the study of IMH, Table 2 and Figure 5 can be used to examine one conclusion from our comparative statics analysis. The usual intuition is that with w and c fixed, percentage contribution declines with group size.[13] However, our comparative statics imply that group size effects should depend on the relative magnitudes of q^* and $\frac{w-1}{N-1}$. Consider, the $w=N$ Chicken game. Since $\frac{w-1}{N-1} = 1$, $\frac{\partial q^*}{\partial N} \geq 0$ for <u>any</u> distribution $F(\cdot)$. This may explain why we observed slightly more participation in the 5 of 7 game

than in 5 of 5. However, since the comparative statics pertain only to local values of derivatives, neither the higher rate in the 5 of 7 games nor the lower participation rate in the 5 of 9 games provide a conclusive test of the comparative statics.

6. Extensions and Conclusions

In this section we discuss two potentially useful directions for generalizing the model we have developed here. The first has to do with applying the basic methodology of sections 2-4 to "variable contributions" public goods problems. The second relates to our choice of how to model the unobserved preferences.

A. Variable Contribution Games.

In the games we analyzed, participants had to make a binary choice. In many other public good situations, it is natural to model an individual's choice as a variable level of contribution and model the total public good level as a continuous increasing function of total contribution, rather than as a binary outcome based on a threshold.

Consider the following extensions of the binary game, where we will denote the level of i's contribution by x_i, the total production of the public good by $X = \sum_{i=1}^{N} x_i$, the (constant) cost per unit of contribution by c, and the value to individual i of the total amount of public good by a concave function $V_i(X)$. Assuming separability, as before, we write

$$U(X, x_i) = V(X) - cx_i + D_i(x_i)$$

where $D(x_i)$ is the additional (altruistic) benefit i gets from contributing x_i

units of the public good. If we make an assumption that i contributes only in discrete units, the problem simplifies considerably. Let d_j^i be the marginal altruistic benefit to i of contributing a unit, given that i is already contributing j-1 units so $D_i(x_i) = \sum_{j=1}^{x_i} d_j^i$. Suppose we assume a similar information structure as before, i.e., each i knows d_j^i $\forall j$, but only knows the distribution function (F_j) according to which the others' d_j^k were (identically and independently) drawn. We conjecture that a Bayesian equilibrium to this "continuous" contribution game is a simple generalization of the d*-equilibria of the binary game. It is a set of cutoff points $(d_1^*, \ldots d_k^*, \ldots)$, one for each contribution level, which define the following decision rule:

Each individual i contributes j_i^* units where

$$j_i^* = \max \left\{ j \mid D_i(j) \geq \sum_{k=1}^{j} d_k^* \right\}.$$

A reason for pursuing this direction is that there are frequent naturally occurring public goods problems of this sort, and these problems have led many experimentalists to use exactly this structure of payoffs (of the distribution of the d_j^i's are still not controlled in the laboratory environment). We have in mind here particularly the experiments conducted by Marwell and Ames (1979, 1980, 1981), Kim and Walker (1984), Isaac, McCue and Plott (1982), and Isaac, Walker and Thomas (1984).

These experiments differed from the binary contribution games of Dawes et. al. (1985) and Simmons et al. (1983) in several important ways. First, as we just noted, the payoff structure was not binary, but allowed <u>variable levels</u> of contribution and public good. Second, the incentive structure was a generalized version of the <u>prisoner's dilemma</u> rather than the chicken → flush

game. That is, if it were common knowledge that $d_j^i = 0$ for all i and j, and the experiment was not "repeated", then everyone would have a dominant strategy of not contributing anything (i.e., V (x) < c for all levels of x). Third, the game was repeated for several trials with the same group and the outcomes were publicly announced after each trial. This latter feature introduces many interesting features not present in a static setting - such as learning and the possibility of adjusting one's decisions in response to other players' contribution choices. These features may be expected to induce systematic changes from trial to trial of the equilibrium $\{d_j\}$ vector, which should lead to a systematic pattern in the evolution of these contribution levels over time.

B. Alternative models of privately known preferences.

We assumed that the nature of each individual's privately known component of preferences was his degree of altruism, which was assumed to be independent of the level of contribution by others. There are many alternative ways to introduce heterogeneity in preferences, each of which may explain variations in the experimental data with varying degrees of success. We chose a model of "pure altruism" because of the preponderance of casual evidence from experiments that many subjects contributed when this was clearly against their best interests in the absence of altruism. Our model of altruism was the simplest one we could think of and was therefore a natural first step. Other possibilities are discussed briefly below:

<u>1. Simple Conditional Altruism</u>. This relaxes the strong assumption that one's own altruistic benefit is independent of the level of contribution of others. For example, in the binary contribution game, suppose that d = 0 if

less than w-1 other individuals contribute, otherwise it is exactly what we defined it to be in section 3. That is, you get no altruistic benefit from contributing unless the public good is produced when you contribute. One can easily derive the equilibrium conditions. The right hand side of these new equalities equal the right hand side of the corresponding equalities in (5) divided by the probability that at least w-1 other individuals contribute. (P^{N+}_{w-1} in the Appendix.)

It is then straightforward to show this "conditioning" leads to a higher d^* in equilibrium and thus lower contribution levels. This is not surprising, since, assuming $F(\cdot)$ is the same in both cases, conditional altruism is "less altruistic" than unconditional altruism.

2. General Conditional Altruism. One could let d_i be a general (not necessarily increasing) function of the number of other contributors. We have not investigated this because the number of other contributors was typically not revealed to experimental subjects.

3. Altruism based on other's public goods benefits instead of the "act" of contributing. We assumed that altruistic benefit was derived from the act of contributing. An interesting alternative model, which is similar in spirit to general conditional altruism, is one in which altruistic benefits are a function of the total benefits one confers on the rest of the group as a result of making a contribution.

4. Non-altruistic models of privately known von Neumann-Morgenstern utilities. An implicit assumption we have made is that the dollar payoffs to individuals correspond exactly (or at least in an increasing linear way) to the non-altruistic component of utility payoffs. If this is not the case, either because of different degrees of risk aversion or varying "intensities"

of preferences which are privately known to the players, then a slightly different version of Bayesian game approach is appealing. These non-altruistic uncertainty models are formally quite similar to the altruistic models in that they include privately known parameters in the payoff matrix. However, they differ in one very important way - namely, they assume that the ordinal preferences induced by the experimenter are preserved. There is a growing body of experimental data which indicates that for many individuals in these experiments, ordinality is not successful induced. The most persistent observation of this sort is that a substantial percentage (roughly 25%) of individuals contribute when non-contribution is a strictly dominant strategy in terms of monetary payoffs.[14] This type of behavior is consistent with either a conditional or an unconditional specification of altruism. It is not consistent with a model in which the only source of private information is risk aversion.

In summary, we have pursued two objectives in this paper. First, we have analyzed a theoretical model of voluntary contributions in binary choice discrete public goods environments, based on asymetric information. The motivation for this analysis comes both from common real-world situations and from an expanding body of systematic experimental results. Consequently, our second purpose was to confront the conclusions of our theory with the experimental data, focusing on one of several implications of the theory, the Inverse Monotonicity Hypothesis. Although the data were broadly consistent with the hypothesis, it would be difficult to argue definitive empirical claims, since the data set we analyzed is quite small and restricted to very little parametric variation.

Appendix

In developing the comparative statics, the following notation will be used:

$$P_k^N(q) = \binom{N-1}{k} q^k(1-q)^{N-1-k}$$

$$P_k^{N+}(q) = \sum_{j=k}^{N-1} P_j^N(q)$$

$$P_k^{N-}(q) = \sum_{j=0}^{k} P_j^N(q)$$

Except for changes in α, we obtain comparative statics for d^* only. With this one exception, the comparative statics of q^* always have the opposite sign. We omit analysis of Control; analysis of that case is straightforward given our treatment of Chicken.

<u>Chicken</u>

1. $\frac{\partial d^*}{\partial c}$

Differentiating (5a) gives

$$\frac{\partial d^*}{\partial c} = \frac{1}{1-f(d^*)\,\frac{\partial P_{w-1}^N}{\partial q}}$$

where $\frac{\partial P_{w-1}^N}{\partial q} = \frac{w-1-(N-1)q}{q(1-q)} P_{w-1}^N(q)$

Therefore, $\frac{\partial d^*}{\partial c} > 0$ if (a) $q^* \geq \frac{w-1}{N-1}$

or if (b) $q^* < \frac{w-1}{N-1}$ and $f(d^*) < \frac{1}{\frac{\partial P_{w-1}^N}{\partial q}}$

Condition (b) essentially says that we are guaranteed the intuitive result $\frac{\partial d^*}{\partial c} > 0$ in the case of equilibria that are <u>stable</u> by the Cournot adjustment procedure and other related criteria.

An example of an unstable equilibrium where the last inequality is violated is illustrated by the point labeled U in Figure 4. Graphically, such equilibria only occur when the graph of the equation $q = 1 - F(d)$ cuts the graph of equation (5) from below.

<u>No Fear, No Greed, Control</u>

By similar argument, $\frac{\partial d^*}{\partial c} > 0$ at all stable equilibria.

2. $\frac{\partial d^*}{\partial \alpha}$, $\frac{\partial q^*}{\partial \alpha}$

<u>Chicken</u>

Again differentiating (5a) gives

$$\frac{\partial d^*}{\partial \alpha} = \frac{\frac{\partial F}{\partial \alpha} \cdot \frac{\partial P_{w-1}^N}{\partial q}}{1-f(d^*)\,\frac{\partial P_{w-1}^N}{\partial q}}$$

Since $\frac{\partial F}{\partial \alpha} < 0$, $\frac{\partial d^*}{\partial \alpha} > 0$ if $q^* \geq \frac{w-1}{N-1}$. If $q^* < \frac{w-1}{N-1}$ and $f(d^*) < \frac{1}{\frac{\partial P_{w-1}^N}{\partial q}}$

(i.e., the equilibrium is stable), then $\frac{\partial d^*}{\partial \alpha} < 0$. Therefore, for stable equilibria, the sign of $\frac{\partial d^*}{\partial \alpha}$ switches at $q^* = \frac{w-1}{N-1}$. It is easily established that $\frac{\partial q^*}{\partial \alpha} > 0$ at all stable equilibria.

No Fear

Differentiating (5b) gives

$$\frac{\partial d^*}{\partial \alpha} = \frac{\frac{\partial F}{\partial \alpha}\left[\frac{\partial P^N_{w-1}}{\partial q} - c\,\frac{\partial P^{N+}_{w-1}}{\partial q}\right]}{1 - f(d^*)\left[\frac{\partial P^N_{w-1}}{\partial q} - c\,\frac{\partial P^{N+}_{w-1}}{\partial q}\right]}$$

If $\left[\frac{\partial P^N_{w-1}}{\partial q} - c\,\frac{\partial P^{N+}_{w-1}}{\partial q}\right] < 0$ then $\frac{\partial d^*}{\partial \alpha} > 0$. If $\left[\frac{\partial P^N_{w-1}}{\partial q} - c\,\frac{\partial P^{N+}_{w-1}}{\partial q}\right] > 0$ then $\frac{\partial d^*}{\partial \alpha} < 0$ if and only if d^* is a stable equilibrium. Referring to Figure 1, $\frac{\partial P^N_{w-1}}{\partial q} - c\,\frac{\partial P^{N+}_{w-1}}{\partial q}$ is negative if and only if $q^* > \hat{q}_{NF}$ (defined in Figure 1). One can show that this will generally be the case either if $q^* > \frac{w-1}{N-1}$ or if $d^* > 0$. However, these latter two are only sufficient conditions. As in Chicken, $\frac{\partial q^*}{\partial \alpha} > 0$ at all stable equilibria.

No Greed

The analysis is parallel to No Fear. If $\left[\frac{\partial P^N_{w-1}}{\partial q} - c\,\frac{\partial P^{N-}_{w-1}}{\partial q}\right] < 0$ then $\frac{\partial d^*}{\partial \alpha} > 0$. If $\left[\frac{\partial P^N_{w-1}}{\partial q} - c\,\frac{\partial P^{N-}_{w-1}}{\partial q}\right] > 0$ then $\frac{\partial d^*}{\partial \alpha} < 0$ if and only if d^* is a

stable equilibrium. Referring to Figure 3, $\frac{\partial P^N_{w-1}}{\partial q} - c\,\frac{\partial P^{N-}_{w-1}}{\partial q}$ is positive if and only if $q^* < q_{NG}$ (defined in Figure 3). One can show that this will generally be the case if either $q^* < \frac{w-1}{N-1}$ or if $d^* > 0$. Also, $\frac{\partial q^*}{\partial \alpha} > 0$ at all stable equilibria.

3. $\frac{\partial d^*}{\partial N}$, $\frac{\partial d^*}{\partial w}$.

Chicken: Differentiation of (5a) and rearranging yields:

$$\frac{\partial d^*}{\partial N} = \frac{\frac{-\partial P^N_{w-1}}{\partial N}}{1 - f(d^*)\,\frac{\partial P^N_{w-1}}{\partial q}}$$

We will treat N as a discrete variable, and evaluate the derivative $\frac{-\partial P^N_{w-1}}{\partial N}$ by the first difference between N-1 and N:

$$P^N_{w-1} - P^{N-1}_{w-1} = P^{N-1}_{w-1}\left[\frac{(N-1)(1-q)}{N-w} - 1\right]$$

$$< 0 \quad \text{iff} \quad q > \frac{w-1}{N-1}$$

As derived earlier, $\frac{\partial P^N_{w-1}}{\partial q} < 0$ iff $q > \frac{w-1}{N-1}$. Therefore, when $q > \frac{w-1}{N-1}$, both the numerator and the denominator of $\frac{\partial d^*}{\partial N}$ are positive, so $\frac{\partial d^*}{\partial N} > 0$ as long as $q^* > \frac{w-1}{N-1}$. If $q^* < \frac{w-1}{N-1}$, then $\frac{\partial d^*}{\partial N} < 0$ when d^* is a stable equilibrium. This parallels the results for $\frac{\partial d^*}{\partial \alpha}$. We add the caveat that if q^* is close to

$\frac{w-1}{N-1}$ this comparative static may be inaccurate (although $\frac{\partial d*}{\partial \alpha}$ will be close to 0 in that case anyway), since our evaluation of $\frac{\partial d*}{\partial N}$ mixes a non-local change in one variable (N) and a local change in another variable (q). This applies to the analysis below, as well.

To sign $\frac{\partial d*}{\partial w}$, we follow a similar line of argument. Differentiation of (5b) yields:

$$\frac{\partial d*}{\partial w} = \frac{\dfrac{-\partial P^N_{w-1}}{\partial N}}{1 - f(d*) \dfrac{\partial P^N_{w-1}}{\partial q}}$$

We treat w as a discrete variable and evaluate $\frac{\partial P^N_{w-1}}{\partial N}$ using the first difference between w-1 and w:

$$P^N_{w-1} - P^N_{w-2} = P^N_{w-1}\left[1 - \frac{(w-1)(1-q)}{(N-w-1)q}\right]$$

$$> 0 \quad \text{iff} \quad q > \frac{w-1}{N}$$

Therefore, when $q* > \frac{w-1}{N-1}$ (and hence $q* > \frac{w-1}{N}$), $\frac{\partial d*}{\partial w} < 0$. If $q* < \frac{w-1}{N}$ and the equilibrium is stable then $\frac{\partial d*}{\partial w} > 0$.

<u>No Fear</u>: Differentiation of (5b) gives

$$\frac{\partial d^*}{\partial N} = \frac{c\dfrac{\partial P^{N+}_{w-1}}{\partial N} - \dfrac{\partial P^N_{w-1}}{\partial N}}{1+f(d^*)\left[c\dfrac{\partial P^{N+}_{w-1}}{\partial q} - \dfrac{\partial P^N_{w-1}}{\partial q}\right]}$$

It is easily shown that $\frac{\partial P^{N+}_{w-1}}{\partial N} > 0$ and $\frac{\partial P^{N+}_{w-1}}{\partial q} > 0$. Therefore, $\frac{\partial d^*}{\partial N} > 0$

if $q^* > \frac{w-1}{N-1}$. If $q^* < \frac{w-1}{N-1}$ the sign is ambiguous.

We also have:

$$\frac{\partial d^*}{\partial w} = \frac{-c\; P^{N+}_{w-1} - \dfrac{\partial P^N_{w-1}}{\partial w}}{1+f(d^*)\left[c\dfrac{\partial P^{N+}_{w-1}}{\partial q} - \dfrac{\partial P^N_{w-1}}{\partial q}\right]}$$

First recall that $\frac{\partial P^N_{w-1}}{\partial w} \gtrless 0$ iff $q^* \gtrless \frac{W-1}{N}$. If $q^* > \frac{w-1}{N-1}$, then the numerator is negative and the denominator is positive, so $\frac{\partial d^*}{\partial w} < 0$. If $q^* < \frac{w-1}{N-1}$ the sign is ambiguous.

<u>No Greed</u>.

Using similar arguments to the No Fear case, one can show that if $q^* < \frac{w-1}{N-1}$ then $\frac{\partial d^*}{\partial N} < 0$ and $\frac{\partial d^*}{\partial w} > 0$. Otherwise the signs are ambiguous.

FOOTNOTES

1 These include (1) social-psychological explanations based on concepts such as fear and greed [Simmons et. al. (1983)]; (2) the minimum contributing set [van de Kragt et. al. (1983)]; (3) pure strategy Nash equilibrium [Palfrey and Rosenthal (1984) and Calvert and Wilson (1984)]; and (5) mixed strategy Nash equilibrium [Palfrey and Rosenthal (1984)]. More recently, Rappaport (1985) has proposed an expected utility decision theoretic model. Our approach differs significantly from his in that we model the social dilemma as a game of incomplete information about altruism and close the model by imposing the consistency requirements of Bayesian Nash equilibria.

2 Relevant papers for our purposes include Darley and Latanè (1968), Dawes et. al. (in press, 1985), Isaac et. al. (1984), Isaac et. al. (1982), Kim and Walker (1984), Marwell and Ames (1979, 1980, 1981), Simmons et. al. (1983), and Van de Kragt et. al. (1983).

3 This observation has been made by Cox et. al. (1982) with regard to auction experiments. They also attempt to explain observations by explicitly incorporating unobservable (or at least uncontrolled) preferences into a theoretical model.

4 Lipnowski and Maital (1983) suggest that this bimatrix structure can also be used to analyze aspects of games with continuous contributions to the production of a continuous public good output.

5 This includes work by both psychologists and economists and is far too extensive to summarize here. See, for example, the collection of papers in Kahneman, Slovic and Tversky (1982).

6 In what follows, we will usually be assuming that F is twice continuously

differentiable and F′ > 0 over a closed interval [$\underline{d}$,$\bar{d}$] where $\underline{d} < -1$ and $\bar{d} > 1$.

Since c < 1, malevolents have negative altruism levels.

The results contained in Palfrey and Rosenthal (1984, 1985) can be easily extended to provide rigorous development of the existence of equilibrium and of asymptotic properties for the games analyzed in this paper.

Bliss and Nalebuff (1985) treat the threshold game with w=1. However, unlike our setup where all players must move simultaneously, in their model players choose a delay time, contributing only if no other player has contributed by this time. In both their game and ours, players' strategies depend on a single private cost parameter (i.e. d_i in our game). Their game avoids the inefficiency of over contribution but generates inefficiency in the form of delay costs. Extending their game to w>1 would constitute one of many interesting avenues for the analysis of dynamic threshold games.

For example, in 1984 Metropolitan Life offered to absorb the (solvent) life insurance subsidiaries of the bankrupt Charter group <u>if</u> individual holders agreed to convert at least 25 percent of the total value of Charter tax shelter annuities to Metropolitan annuities that paid a lower rate of interest. See Letter from Metropolitan Life Insurance Company to Charter Security Life policyholders, December 1, 1984.

April 29, 1985, p. 61.

See Hansen et. al. (1986) for use of a similar approach in estimating the distribution of voting costs using aggregate election data.

13 See Darley and Latané (1968) who found support for this group size hypothesis with $w=1$ and $N=1$, 3, and 5 in an experiment with unstructured payoffs, but which nonetheless could be viewed as a binary contribution Chicken game.

14 This occurs on the (publicly known) last trial of multi-game experiments [Isaac, Walker, and Thomas (1984)] and in single shot experiments both with and without visual contact between contributors and beneficiaries Van de Kragt et al. (1986)]. Isaac, Walker, and Thomas (1984, p. 141) conclude, "We conjecture ... [there are] a core of people for whom utility functions are not completely selfish or who otherwise wish to behave in 'good guy' fashion."

The pattern of contribution observed in these experiments is also instructive. First, when participants can choose among several levels of contribution, a full range of levels is observed, even in the last round. Second, the amount of contribution can be manipulated by varying the benefit of defection relative to the marginal value of contribution. These observations suggest that there is considerable variation in the degree of selfishness in the subject pools and that individuals trade off their personal benefits against the social value of cooperation.

BIBLIOGRAPHY

Bliss, Christopher and Barry Nalebuff (1984), "Dragon-Slaying and Ballroom Dancing: The Private Supply of a Public Good", *Journal of Public Economics*, 25:1-12.

Calvert, Randall and Wilson, R. (1984). "Comment [on Van de Kragt, et. al. (1983)]", *American Political Science Review*, 78, 456-497.

Cox, J., Roberson, B., and Smith, V. (1982). "Theory and Behavior of Single Object Auctions", in Research in Experimental Economics (ed. Vernon Smith), JAI Press, pp. 1-43.

Darley, John M. and Bibb Latané, (1968). "Bystander Intervention in Emergencies: Diffusion of Responsibility". *Journal of Personality and Social Psychology*, 8, 377-383.

Dawes, Robyn M. (1980). Social Dilemmas. *Annual Review of Psychology*, 31, 169-193.

Dawes, Robyn M., John M. Orbell, and Alphons J. C. van de Kragt, (1985). A "Great Society" of a "Small Society"?: The Threshold-of-the-room effect in Social Dilemmas, paper presented at the annual meeting of the Western Psychological Association, San Jose, April, 1985.

Grossman, Sanford J. and Oliver D. Hart (1980). Takeover bids, the free-rider problem, and the theory of the corporation. *Bell Journal of Economics*, 11, 42-64.

Hansen, Stephen, Thomas R. Palfrey, and Howard Rosenthal (1986). The Downsian Model of Participation: Formal Theory and Empirical Analysis of the Constituency Size Effect. *Public Choice*, 52, 15-34.

Harsanyi, John (1967-68). Games with incomplete information played by Bayesian players, I-III. *Management Science,* 14: 149-182, 320-334, 486-502.

Hildebrand, David K., James D. Laing, and Howard Rosenthal, *(1977). Prediction Analysis of Cross Classifications*. New York: Wiley.

Isaac, R. Mark, James M. Walker, and Susan H. Thomas (1984). Divergent evidence on free riding: An experimental examination of possible explanations. *Public Choice*, 42: 113-149.

Isaac, R. Mark, Ken F. McCue, and Charles R. Plott (1985). Public goods provision in an experimental environment. *Journal of Public Economics*, 26: 51-74.

Kahneman, Daniel, Paul Slovic, and Amos Tversky, eds. (1982). Judgement under Uncertainty: Heurstics and Biases, New York: Cambridge Press, 1982.

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

Lipnowski, Irwin and Shlomo Maital (1983). Voluntary Provision of a Pure Public Good as the Game of Chicken, Journal of Public Economics, 20: 381-386.

Luce, R. Duncan and Howard Raiffa (1957). *Games and Decisions*. New York: Wiley.

Marwell, Gerald and R. Ames (1979). Experiments on the provision of public goods I: Resources, interest, group size, and the free rider problem. *American Journal of Sociology*.

_________ (1980). Experiments on the provisional public goods II: Provision points, stakes, experience, and the free rider problem. *American Journal of Sociology*, 85: 926-937.

_________ (1981). Economists free ride, does anyone else: Experiments on the provision of public goods, IV. *Journal of Public Economics*, 15: 295-310.

Palfrey, Thomas R. and Howard Rosenthal (1984). Participation and provision of discrete public goods: A strategic analysis. *Journal of Public Economics*, 24: 171-193.

Palfrey, Thomas R. and Howard Rosenthal (1985). Voter Participation and Strategic Uncertainty. *American Political Science Review*, *79*, 62-78.

Rappaport, Ammon. Public Goods and the MCS Experimental Paradigm, *American Political Science Review*, 79, 148-155.

Roberts, Russel D. (1984) A Positive Model of Private Charity and Public Transfers. *Journal of Political Economy*, 92, 136-153.

Van de Kragt, Alphons, John M. Orbell and Robyn Dawes (1983). The Minimal Contributing Set As a Solution to Public Goods Problems. *American Political Science Review*, 77, 112 - 121.

Van de Kragt, Alphons J.C., Dawes, Robyn M., and John M. Orbell with Sanford R. Braver and L. A. Wilson II, (1986). Doing Well and Doing Good As Ways of Resolving Social Dilemmas. In Wilkes, H.,et al. eds., *Experimental Social Dilemmas*, Frankfurt am Main: Verlang Peter Lang, 177-203.

Table 1.

Payoff Functions for Selected Contribution Games

Game Description	Contributors $v(m_i,1)$ $m_i>w-1$	$m_i=w-1$	$m_i<w-1$	Non-Contributors $v(m_i,0)$ $m_i>w-1$	$m_i=w-1$	$m_i<w-1$
Chicken	1-c	1-c	-c	1	0	0
No Fear	1-c	1-c	0	1	0	0
No Greed	1-c	1-c	-c	1-c	0	0
Control	1-c	1-c	0	1-c	0	0
Poison	1-c	1-c	1-c	1	0	0
Dominant	1-c	-c	-c	1	0	0
Incremental	bm_i-c	bm_i-c	bm_i-c	bm_i	bm_i	bm_i

Note: Relative to the experimental games, we have, for expositional convenience, renormalized payoffs so that "Table Entries = 0.1×Dollar Payoffs - 0.5." In all experiments analyzed except Incremental, c=0.5. In Incremental, c=0.6 and b=0.2. The games other than Incremental are "threshold" games where w denotes the threshold of contributions needed to produce the "public" good. In the experimental runs of Chicken, No Fear, and No Greed, groups of size N=5, 7, or 9 were used with w=3 or 5. In Dominant, the effective value of N was 5 and w was set to 4.

Table 2.

Comparative Statics of Stable Equilibria to Threshold Games

Results are for $\frac{\partial d^*}{\partial \cdot}$

Parameter	Chicken, Control q^* $<\frac{w-1}{N-1}$	$>\frac{w-1}{N-1}$	No Fear q^* $<\frac{w-1}{N-1}$	$>\frac{w-1}{N-1}$	No Greed q^* $<\frac{w-1}{N-1}$	$>\frac{w-1}{N-1}$
c, cost of contrib.	+	+	+	+	+	+
α, altruism distribution	-	+	?	+	-	?
N, group size	-	+	?	+	-	?
w, threshold	+	-	?	-	+	?

Notes: Some refinement of results in ? ranges is in the Appendix.

Results for $\frac{\partial q^*}{\partial \cdot}$ have sign opposite to that in table

except that $\frac{\partial q^*}{\partial \alpha}$ is always positive.

Table 3

Analysis of Dawes-Orbell-Simmons-Van de Kragt
No Discussion Experiments

Experiment	Number of Contributors	Total Subjects	Estimate of q^*	d^* Values
Chicken 3 of 7	36	70	0.514	0.279
No Fear 3 of 7	30	49	0.612	0.355
No Greed 3 of 7	60	70	0.857	-0.002
Chicken 5 of 7	45	70	0.643	0.173
No Fear 5 of 7	32	49	0.653	-0.002
No Greed 5 of 7	65	70	0.929	-0.025
Chicken 5 of 9	42	90	0.467	0.231
Chicken 5 of 5	16	25	0.640	0.332
Dominated 4 of 9	19	63	0.302	0.500
Incremental	21	56	0.375	0.600

Figure 3 Equilibrium Correspondence 3 Of 7 Games

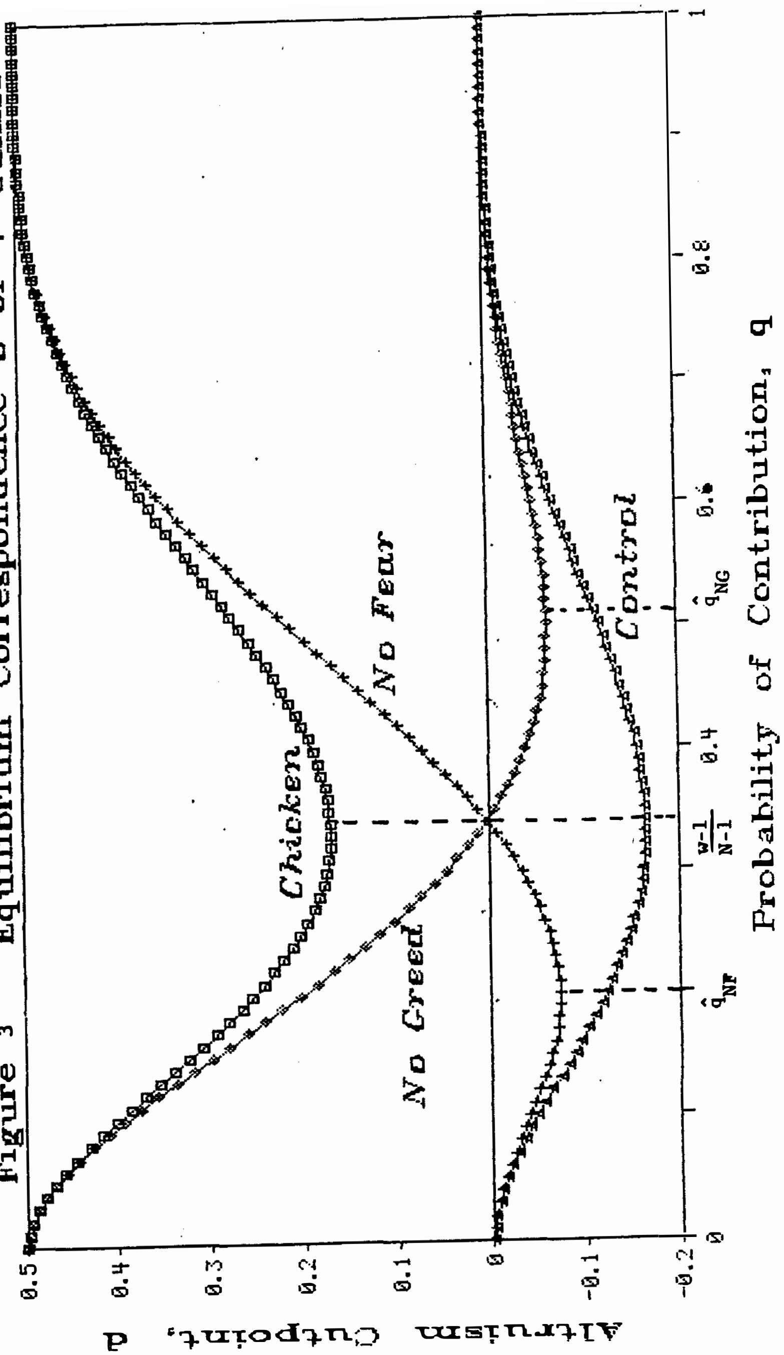

Figure 4   Equilibrium Correspondence 5 Of 7 Games

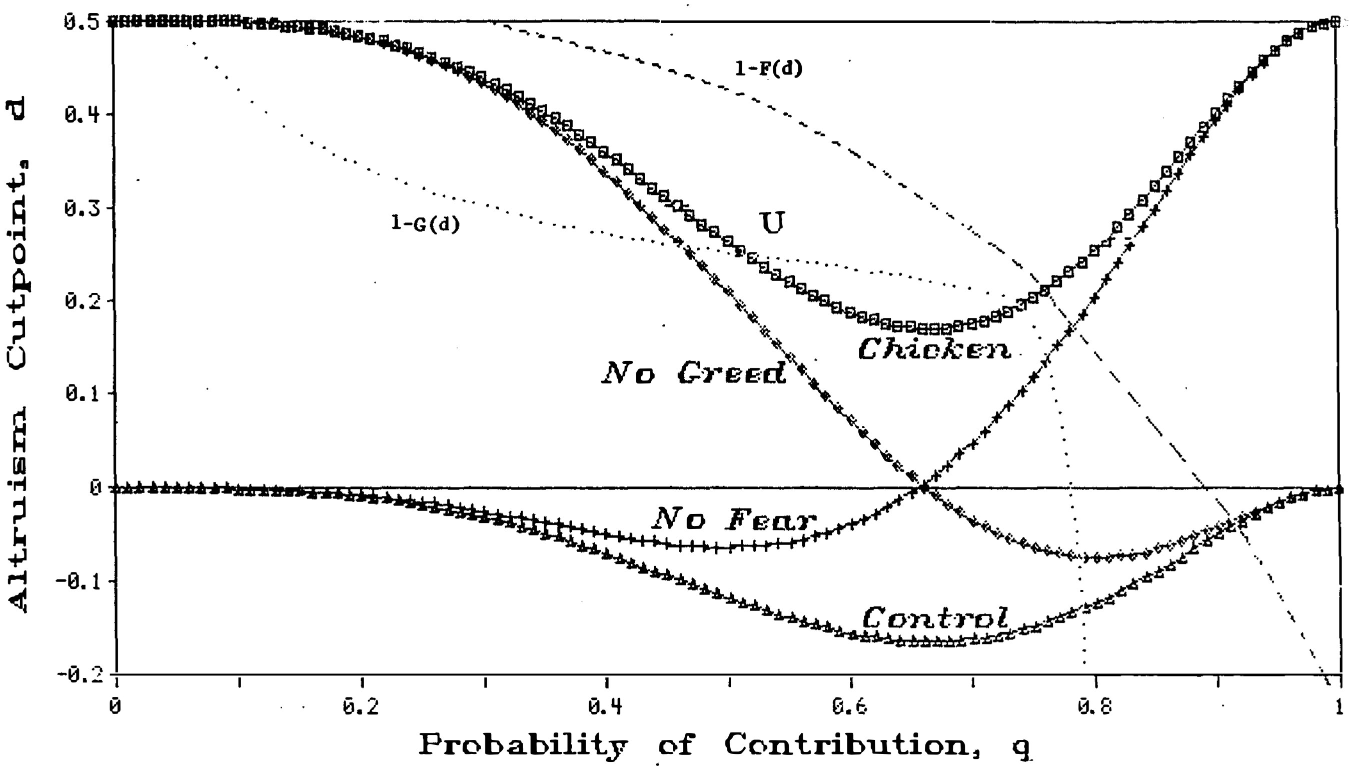

Figure 5   Altruism Cutpoints, Experimental Data.