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Workshop in Political Theory and Policy Analysis

Is There a Problem with Public Good Provision

John O. Ledyard
California Institute of Technology
Pasadena, CA

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DRAFT

This is a *very rough draft* of a paper prepared for a conference on experimental research on the provision of public goods and common-pool resources in Bloomington, Indiana.

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Indiana University
513 North Park
Bloomington, Indiana 47405-3186

independently by theorists, usually economists and game theorists, and experimentalists, usually psychologists and sociologists, each group believing that the other was following an incorrect and misguided path. A caricature of the results and approaches would be as follows. Theorists believe one of two things: (a) no one would contribute to the voluntary provision of a public good because it is a dominant strategy not to do so or (b) bargaining and communication will always guide groups to provide the efficient level of public goods. The former view is usually attributed to economists (who are known to be the only truly selfish academics). The latter view can be found in Lindahl [.] or Johansen [103]. Experimentalists know better. They have found that voluntary contributions are greater than zero but less than 100 percent efficient. See either Dawes and Thaler [51] or Isaac and Walker [97] for recent summaries of the data. The statement found in the former is "It is certainly true that there is a 'free rider problem'. ...On the other hand, the strong free rider prediction is clearly wrong." In summary, it seems that either anything can happen or we have lost control in our experimental work. One must hope neither is correct. Let us see whether we can come up with a better and more precise understanding of the situation.

2.1 Experimental Evidence

Let us begin by trying to discover what determines the level of contribution towards the production of a public good. In the language of the previous section, we want to determine the function $\mu(e,(M,g))$ for as many public goods environments e and for as many mechanisms (M,g) as possible. Ideally, we would not want this model to be ideosyncratically dependent on one institution. Nevertheless we begin with a simpler question. What are the details of the following equation for mechanisms which use voluntary contributions:

$$\text{contributions} = \text{f(environment, altruism, thresholds, ...)}$$

I have found it useful to group the variables identified by existing research into three main categories: the *environment* (numbers, strength of incentives, extent of homogeneity, thresholds imposed by the production technology, initial information structure, ...), *systemic variables* (fairness

so vague

why strength of incentive ∈ envir
unanimity rules ∈ C design vars
incentives = f(dec rules + other factors)??

concepts, altruism, risk attitudes, sex, beliefs, ...), and *design variables* (such as unanimity rules, structured communication, thresholds imposed by the institution, and moral suasion). I have chosen these categories to emphasize two things. First, with current experimental technologies, some of these variables (effects) are more easily controlled by the experimentalist than others. Those identified as environmental can be controlled, while those listed as systemic seem difficult to control. As we will see, I believe strongly that the extent of control exhibited by the experimenter is fundamentally important to the constraints placed on the theorist by the data and to the ability of theory to guide experiments. Second, there are exogenous variables or effects identified by experimentalists which more properly should be identified as institutional designs. These variables are amenable to change and the mechanism designer can use them to improve the performance of solutions to the free rider problem.

In Table 1, I summarize what seems to be the consensus of experimentalists about the effect of a change in one of these variables on the total contributions as a percent of the efficient level. Some effects are more certain than others. Left unexplained in the table are the actual levels of contribution and cross-effects. The latter are very important and not well tracked in the literature.[9] [I hope to have a more detailed breakdown by the time this goes to press].

2.2 Discussion

2.2.1 Dilemmas versus Chickens

To understand the role of thresholds one must recognize that there is a fundamental difference in the structure of a Prisoner's dilemma game (no threshold) and the game of chicken (with threshold). In the former it is a dominant strategy[10] not to cooperate and, therefore, there is (usually) a unique non-cooperative equilibrium which is not pareto-optimal. In the

[9] For example, communication in chicken games seems to increase efficiency while communication in dilemmas may in fact lower efficiency. See Section 2.1.

[10] A strategy is dominant if it maximizes the return to an individual no matter what his opponents do. That is, if player i's strategy is c and the others' strategies are x and i's payoff is $u(s,x)$ then the strategy c is dominant if and only if c solves $\max u(c,s)$ for all possible s.

Table 1: Stylized Facts

	Effect on %C	Relevant Section
I. ENVIRONMENT—controllable		
Thresholds	+	2.2.1
MPCR (marginal per capita return)	+	3, 3.1
Numbers	?	3.1
Experience	-	2.3.2
Homogeneity	+	2.2.3, 3.2
Iteration	N.A.	2.3.2
Economics Training	-	2.3.2
Common knowledge	?	
II. SYSTEMIC—not controlled		
Altruism	+	3
Risk Attitudes	?	
Beliefs	?	
Information Processing Capacity	?	
III. INSTITUTION		
Unanimity	−	
Communication	+ or −	2.2.2
Moral Suasion	+	
Thresholds	?	
Rebates	+ or ?	

game of chicken there are generally many non-cooperative equilibria, each of which may be optimal, and the task of the players is to coordinate their actions to select one. This observation has important ramifications for experimental research with public goods. The now classic environment of Marwell and Ames [118] and Isaac and Walker [97] is of the prisoners' dilemma variety. In their world each player is given some number of tokens, z_i, each worth some amount of money, p, which each can donate to the production of a public good. If the total tokens contributed is C, then an amount of the public good worth $G(C)$ is produced and each player receives $u_i = p(z_i - c_i) + \left(\frac{1}{n}\right) G(C)$ where c_i is i's contribution and n is the total number of players. Usually $G(C) = aC$ in which case it is easy to see that i's marginal return from contributing is $-p + (a/n)$ whereas the group marginal return from i contributing is $-p + a$. Thus, if $pn > a > p$ then it is a dominant strategy for each i to contribute $c = 0$ whereas $c = z$ would maximize group contributions. The other classic environment of Dawes et. al. [45], Palfrey-Rosenthal [134], and others is of the chicken variety. In their world each player is given some tokens, z_i, (in many cases only one), each worth some money, p, and which each can donate to the production of a public good. If the total tokens provided is greater than or equal to some prespecified number, K, then one unit of the public good is produced and each i receives r, yielding a total for i of $u = p(z - c) + r$. If less than K tokens are received then no good is produced but the contributors still lose their money.[11] For the simplest case where $z = 1$ for each i and $r > pz$, there is no dominant strategy for any player. If $K - 1$ of the others contribute then i maximizes her payoff by contributing. If some other number contribute then i's best replay is to not contribute. There will be a large number of non-cooperative equilibria; in particular pick any K of the N player to contribute.[12] With symmetry, each equilibrium (except the one in which no one contributes) maximizes group payoff but yields a different distribution of rewards.

It is not surprising that we see different results in these two types of envi-

[11] Of course, whether or not they lose their money is a design variable that can be, and has been, manipulated by the experimenter. See Dawes, Orbell and van de Kragt [48]. In those experiments the chicken structure was still maintained and the group optima still were to have some K contribute.

[12] It should be noted that everyone not contributing is also a non-cooperative equilibrium.

ronments. For example, if the players can talk and if there is to be repeated play then one might suspect that in the game of chicken they would correlate their strategies and rotate the coalition K that contributes in a way that equalizes sacrifice. Experimental evidence confirms this hypothesis. See for example Chamberlin [33] and Dawes et. al. [49]. But one might expect that communication would have a lesser effect in dilemma games since more is involved than simple coordination. For data supporting these expectations, see Dorsey [53], Isaac and Walker [97], and Banks, Plott and Porter [8]. The theory remains undeveloped, which is not surprising since with repetition and communication there are very complicated games. It remains to be shown that either stated intuition or loose but compelling experimental data are consistent with any sensible model of behavior.

A final remark on thresholds is in order. One must be careful to differentiate between those which are due to the environment and those which are institution design choices. An example of the former is the construction of a bridge which is of zero use unless fully completed.[13] An example of the latter is a target set for contributions such that all pledges will be returned if that level is not reached. (This example combines the design feature of rebates and thresholds). One might assume, since contributions tend to be higher with thresholds than without, that they would serve a useful design function. This remains, however, an open question. The trade-off is that although contributions are higher, production of any public good must be foregone if the chosen level is not attained. If produced there will be a higher level of the good but this implies a higher probability of non-production. More research is needed on the trade-offs although Isaac, Schmidtz and Walker [98] is a beginning.[14] [More later].

2.2.2 Homogeneity

[More to come.]

2.2.3 Communication

[More to come.]

[13] This abstracts from the choice of a 1-lane or a N-lane bridge.

[14] Banks, Plott, Porter [8] does examine this type of trade-off when the design choice is unanimity or not.

2.3 Puzzles

2.3.1 Why does Plott always get less contributions?

In an early example of experimental economics research with externalities, Plott [140] provides data on the environment summarized in Figure 2. This is very close in spirit to a public goods environment. Figure 2 is constructed from $U^j = B^j(x^j) - R(y)$ for $j = 1, ..., J$ and $U^k = C^k(w^k) - R(y)$ for $k = 1, ..., K$ where $y = \Sigma_{j=1}^{J} x^j$ and $\Sigma_j x^j = \Sigma w^k$. In Plott's work a double oral auction is used to allocate x and w with suppliers of w^k selling to buyers of x^j. The data strongly support the hypothesis of non-cooperative behavior. Experimentally, the allocations achieved ignore the effect of $R(y)$. That is (x, w) tends to maximize $\Sigma_j B^j(x^j) - \Sigma_k C^k(w^k)$ subject to $\Sigma x^j = \Sigma w^k$. This indicated by P_N, Q_N in Figure 2. The efficient allocation, which does not occur in Plott's data, would maximize $\Sigma_j B^j(x^j) - \Sigma_k C^k(w^k) - (J+K)R(y)$ subject to $\Sigma_j x^j = \Sigma_k w^k$. This is indicated by P_S, Q_S in Figure 2. Now suppose we match up j's and k's and let $U^i = B^i(x^i) - C^i(x^i) - R(y)$ where $y = \Sigma x^i$. This begins to look very much like a public goods model. A voluntary contributions mechanism would allow i to choose x^i (subject perhaps to $x^i \leq z^i$). If $B^i(x^i) - C^i(x^i) = W(x^i)$ for all i, then the non-cooperative equilibrium remains Q_N in Figure 2 and the social optimum is still Qs. What would happen? As far as I know this remains unstudied in this form with a public bad.[15] But we can push this further. Suppose $B^i(x^i) - C^i(x^i) = px^i$ for all i and that $R(y) = -\frac{ra}{N}y$ for all i. Then $U^i = px^i + \frac{ra}{N}y$ and $\Sigma x^i = y$. This is exactly the Isaac-Walker structure and it is summarized in Figure 3. The non-cooperative equilibrium is $Q_N = 0$ and the socially efficient outcome is Qs. The Plott data suggest, since each individual simply buys from herself, that we should observe $Q = Q_N = 0$. The data from voluntary contributions suggest we get approximately $Q = 45$ percent of Qs. The data from voluntary contributions with communication suggest $Q = 70$ percent of Qs. What is going on here? Is it simply that institutions matter? Or are there "experimenter effects"?

[15] Isaac, McCue, Plott [94] (check this), Smith [165] and Banks, Plott and Porter [8] have studied a very similar model. There $U^i = R^i(y) - x^i$ and $y = \frac{1}{C}\Sigma x^i$. Andreoni [4], with another intention in mind, induced symmetric Cobb-Douglas utilities and found contributions near the non-cooperative equilibrium and not near the "optimal" level. Maybe non-linearities are important. [More later].

2.3.2 What is really happening with repetition?

Repetition (not replication) has become a common feature of much research in experimental economics. Usually this seems to be done in an effort to eliminate or control for at least two types of learning effects: learning how to play the particular class of games, such as what keys to press in a computerized continuous auction or how to read a particular payoff schedule, and learning about the specific game one is in, such as what the environment is and what are the other subjects like. If these were the only phenomena we were interested in, we could easily control for the first type of learning by simply bringing back subjects who had previously participated in similar experiments. This is a common practice and data suggest (see Isaac, Walker, and Thomas [93]) that experienced subjects[16] contribute less that those who are first-timers. It obviously takes time and effort to learn about the implications of one's own behavior in new environments and institutions. But this does not mean one should ignore the data from inexperienced subjects. We have learned that some institutions are more robust to inexperience than others[17] and we would like to find out why. Clearly the voluntary contributions mechanism is not robust to experience. If we want to design a better (more efficient outcomes) institution, we need more research on this topic, including the role of feedback. (See, e.g. Dorsey [53] for a very interesting beginning). An open question arising from Marwell and Ames [119] is whether economics training is simply a substitute for experience or whether economists are self-selected selfish subjects.

We have data to address all of these questions & should do so,

Experimental evidence on the second type of learning is less clear. In early experiments with public goods (e.g., Smith [166]) and in market experiments with private goods, with repetition there appears to be evidence in the data of convergence to a complete information non-cooperative equilibrium. This would imply that repetition of the same environment with the same players helps subjects learn to discover what the appropriate non-cooperative strategy is in these games.[18] However, that learning will be

and CPR experiments

[16]Those who have previously been in a voluntary contributions public goods experiment.

[17]For example, the English ascending bid auction and the second-price auction are "strategically identical" yet in the former even inexperienced subjects use dominant strategies immediately (yielding 100 percent efficiency) while in the latter it may take five or more experiences for subjects to learn the dominant strategy. See Cox, Roberson and Smith [41].

[18]A puzzle (at least to some economists) is why this convergence to equilibrium—a

confounded by strategic considerations and the data generated will generally reflect both effects. The strategic effects I have in mind are the result of repeated play. A good theoretical example arises in the work of Kreps, et. al [107] in which they show that although non-cooperation is dominant strategy in a one-time play of a prisoner's dilemma game, it may be optimal to cooperate early on if the game is to be repeated, especially if rationality is not common knowledge.[19]

Why is it important to know whether it is strategy or learning that leads, for example to a deterioration in contributions[20] after some number of iterations? From a theoretical point of view, one must consider significantly different models depending on what is really happening. It is possible to construct a model in which there is a very small probability that some subjects are not fully rational[21] (i.e., use dominated strategies) and in which even fully rational selfishly maximizing (economists?) subjects would contribute all or most tokens—at least in the early periods. Towards the last iteration, the rational players will not contribute. Thus, one should observe the development of a bimodal distribution in contributions as iteration continues. [See IWW—this conference–for data somewhat like this in large groups].

If, on the other hand, subjects are simply trying to learn (by some suitable groping process) what the appropriate one-trial strategy is, given this environment and this collection of subjects, then the appropriate model would be something like an evolutionary (genetic?) learning algorithm found in Andreoni and Miller (this conference), Crawford [.], or a Bayesian model like that of Jordan [.].

I'm not sure yet how and in what way all of the theoretical predictions of strategic models differ from learning models. That is a theoretical puzzle. The experimental puzzle is to develop experiments which allow separation of these two types of temporal phenomena and identification of those aspects of the environment or institution which speed learning when that is

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rest point—occurs in most private goods experiments and some public goods experiments (such as Plott's) but not in most public goods experiments with voluntary contributions and symmetric payoffs.

[19]Another beautiful example of this can be found in the McKelvey-Palfrey [123] analysis of centipede games.

[20]See Isaac-Walker [97] and Isaac, Walker and Williams [102] for some data.

[21]They may behave, for example, like those modeled in section 3 below.

desirable or channel strategy when that is desirable.

3 A New Theoretical Framework

Without a provision point, it is well-known that if all subjects are rational and if this is common knowledge then we would never see any contributions even with iterations. Therefore, to explain the facts, we need to introduce some irrationality. This might be in the form of stupidity (see Andreoni and Miller [126]) or in the form of non-rational expectations (see Rapoport [143]) and Palfrey-Rosenthal [138]). However, we choose to introduce a small amount of a certain type of altruism. In particular, we will assume that some subjects get some satisfaction (a warm glow) from participating in a group that implicitly and successfully cooperates.[22]

I take off from a remark of Isaac, Walker and Williams [102] and will use a linear model for ease of exposition. Such a model will predict contributions either of zero or of all tokens ($M_i = 0$ or z_i). (To have a model yield partial contributions requires some types of non-linearitics such as risk aversion. The data suggest linearity after a number of rounds but not in opening trials).

Let T be the set of agents who give z_i. We say T is *successful* if and only if

$$\Sigma_T \left[P_i(z_i - M_i) + \frac{1}{N}G(\Sigma_T M_i)\right] \geq \Sigma_T z_i P_i$$

[Note: We could have added $\Sigma_{\sim T} M_j$ in the argument of $G(\cdot)$ but for the linear model $\Sigma_{\sim T} M_j = 0$]. We will assume that each i likes to be in T if and only if T is successful. That is, we assume that i's payoff is

$$\begin{aligned} V^i + \frac{1}{N}G(\Sigma_T M_k) & \quad \text{if } T \text{ is successful and } i \in T \\ \frac{1}{N}G(\Sigma_T M_k) & \quad \text{if } T \text{ is not successful and } i \in T, \text{ and} \\ P_i z_i + \frac{1}{N}G(\Sigma_T M_k) & \quad \text{if } i \notin T \end{aligned}$$

We will assume $V^i \sim H(\cdot)$ where H is a c.d.f which the experimenter can not control but can only estimate from indirect evidence.

[22] It is not obvious this model satisfies my criterion, in Section 2.1, that our behavior model not depend ideosyncratically on one situation. However, it is a start.

For the case of symmetric linear payoffs, $p_i = p$, $z_i = z\ \forall i$ and $G(\Sigma M^i) = a\Sigma M^i$. Then T is successful if and only if $Ta \geq Np$. Let $\tilde{t}$ be the number of others for whom $M_j = z$. In equilibrium, from i's point of view, $\tilde{t}$ is a random variable. If i gives z, then

$$U_i = \frac{az}{N}E(\tilde{t}+1) + V^i \text{ prob}\left(\tilde{t}+1 \geq \frac{Np}{a}\right)$$

where $E(\tilde{t}+1)$ is the expected value of $t+1$. If i gives 0, then

$$U_i = \frac{az}{N}E(\tilde{t}) + pz$$

Therefore i gives z if and only if

$$V^i \geq \left(\frac{Np-a}{N}\right)\frac{z}{\text{prob}\left(\tilde{t} \geq \frac{Np-a}{a}\right)}$$

Since V is distributed according to $H(\cdot)$, the probability that i chooses z is

$$\pi = 1 - H\left[\left(\frac{Np-a}{N}\right)\frac{z}{\text{prob}\left(\tilde{t} \geq \frac{Np-a}{a}\right)}\right]$$

Let

$$F(q;\pi,N-1) = \Sigma_{k\leq q}\begin{pmatrix} N-1 \\ k \end{pmatrix}\pi^k(1-\pi)^{n-k-1}$$

be the probability that less than or equal to q others contribute. $F(q;\pi,N-1)$ is the c.d.f. of $\tilde{t}$. Thus in equilibrium π solves

$$\pi = 1 - H\left[\frac{Np-a}{N}z \cdot \frac{1}{1-F\left(\frac{Np-a}{a};\pi,N-1\right)}\right] \tag{1}$$

Note that for $Np > a$, $\pi^* = 0$ is a solution. (For $Np \leq a$, $\pi^* = 1$ is one solution). But there can be many others. (Note also that if $H(v) = 1\ \forall v \geq 0$ and $Np > a$ then $\pi = 0$ is the only solution. This is the model generally attributed to economists). We will concentrate on stable[23] points for which $\frac{\partial H}{\partial \pi} > -1$. Let us look at the comparative statics of (1) rewritten as

[23]Stability here refers to local stability of the response function $\frac{d\pi}{dt} = 1 - H(\cdot) - \pi$, and not game theoretic stability.

$$H\left[\gamma(\pi, N, p, a, z)\right] + \pi = 1$$

It is easy to see that for $y = N, p, a,$ or z when $dH(\cdot)$ exists,

$$\frac{\partial \pi}{\partial y} = \frac{-h(\cdot)\gamma_y}{1 + h(\cdot)\gamma_\pi}$$

Therefore, by stability,

$$\text{sgn}\left(\frac{\partial \pi}{\partial y}\right) = -\text{sgn}(\gamma_y)$$

For example, it is easy to see that

$$\text{sgn}\left(\frac{\partial \pi}{\partial z}\right) = -\text{sgn}\left(\frac{Np - a}{N}\right) < 0$$

since $Np > a$ by design. It is almost as easy to see that sgn $\left(\frac{\partial \pi}{\partial p}\right) < 0$, since

$$\frac{\partial \gamma}{\partial p} = \frac{z}{1 - F(\cdot)} + \left(\frac{Np - a}{N}z\right)\left(\frac{1}{1 - F}\right)^2 f(\cdot)\frac{N}{a} > 0.$$

[Note: This suggests that if an experimenter wanted to control better for "warm glow" effects, one way would be to increase p. As $p \rightarrow \infty$ all equilibria $\rightarrow \pi = 0$.]

Continuing, $\frac{\partial \pi}{\partial a} > 0$ since

$$\frac{\partial \gamma}{\partial a} = \left[-\frac{z}{N(1 - F)} - \left(\frac{Np - a}{N}\right)\frac{z}{(1 - F)^2}f(\cdot)\frac{Np}{a^2}\right] < 0$$

Finally,

$$\frac{\partial \gamma}{\partial N} = \left[\frac{az}{N^2(1 - F)} + \frac{(Np - a)z\left[\frac{p}{a}f(\cdot) + F_N\right]}{N(1 - F)^2}\right]$$

Therefore,

$$\text{sgn}\left(\frac{\partial \pi}{\partial N}\right) = -\text{sgn}\left[az(1 - F) + N(Np - a)z\left(\frac{p}{a}f(\cdot) + F_N\right)\right]$$

It is very difficult to determine this sign because

$$\begin{aligned} F_N &\cong \Sigma_{k\leq q}\left[\binom{\cdot}{k}\pi^k(1-\pi)^{N-k}-\binom{N-1}{k}\pi^k(1-\pi)^{N-k-1}\right] \\ &= \Sigma_{k\leq q}\binom{N-1}{k}\pi^k(1-\pi)^{N-k-1}\left(\frac{N}{N-k}(1-\pi)-1\right) \end{aligned}$$

If $q < N\pi$ then $F_N < 0$ but if $q > N\pi$ then F_N could be anything.

Let us look at the perturbations suggested by Isaac, Walker, and Williams [102] in their experimental work. They consider (for $p = 1$, z = constant) changes in N and a which keep MPCR $= \frac{a}{Np}$ constant and changes in MPCR which keep N constant. We have already dealt with the latter since $\text{sgn}\frac{\partial\pi}{\partial\ \text{MPCR}} = \text{sgn}\frac{\partial\pi}{\partial a} > 0$.

For the former, let $M = \frac{a}{Np} = MPCR$ and rewrite

$$\gamma(\ ) = pz(1-M)\left[1-\frac{1}{F\left(\frac{1}{M}-1;\pi,N-1\right)}\right]$$

Then

$$\gamma_N = \frac{pz(1-M)}{(1-F)^2}F_N$$

Thus

$$\left(\frac{\partial\pi}{\partial N}\right)_{M=\text{constant}} \leq 0 \text{ if and only if } F_N \geq 0.$$

Further, the effect will be stronger the larger z or p or the smaller M is.

To summarize, letting $N\pi = C$ be the expected (mean) contributions, the model predicts that, given $H(\cdot)$,

$$C = f[N,p,a,z] \equiv N\cdot\pi[N,p,a,z] \tag{2}$$

where π solves (1) and where

$$f_p < 0, f_a > 0, f_z < 0$$

and $f_N = \pi + N\pi_n$ is unspecified. We can also write (2) as

$$C = g(pz,M,N) = N\hat{\pi}(pz,M,N) \tag{3}$$

where $\hat{\pi}$ solves

$$\pi = 1 - H\left[\frac{pz(1-M)}{1 - F\left(\frac{1}{M} - 1, \pi, N-1\right)}\right] \tag{4}$$

Here $g_{pz} < 0, g_M > 0$ and $g_N = N\hat{\pi}_N + \hat{\pi}$ is unknown.[24]

These signs seem to be consistent with the experimental results, but is there a tougher test? How can we tell from the experimental data whether the theory is at all close to the facts? A natural way, introduced by Palfrey and Rosenthal [134], is to note that in each experiment only $H(\cdot)$m which can be viewed as the population distribution, is unknown to the experimenter. Further, the theory predicts that

$$(1-\pi) = H\left[\gamma(pz, M, \pi, N-1)\right]$$

where

$$\gamma(\cdot) = pz(1-M)\left[\frac{1}{1 - F\left(\frac{1}{M} - 1; \pi, N-1\right)}\right]$$

For each experiment, $pz, M,$ and N are controlled and $M_1, ..., M_N$, the contributions are observed. One can compute

$$\delta = \frac{\left(\Sigma_{i=1}^{N} M_i\right)}{N}$$

and then plot $1-\delta$ against $\gamma(pz, M, \delta, N-1)$. That is, use δ as an estimate of π. If the plot is monotonically non-decreasing, as the c.d.f. H should be, then perhaps the model is a good one. If not, we will need to try again. I'm sure there are many non-parametric tests which can be cooked up to study this.

There are two problems with testing this model other than the obvious job of computation. First, the model is really only about behavior in voluntary contributions institutions with experienced players playing once only. Most experiments that have been run once only have been with inexperiences subjects (first-timers). One might be tempted to use the first period of iterated experiments but that would be inappropriate because

[24] We do know that $g_N > 0$ if $F_N \leq 0$ which is true if $\frac{1}{M} - 1 < N\pi$.

of the potential contamination by strategic effects. Second, the data are difficult to discover by simply reading charts in published papers.

In order to carry out serious empirical testing of this model one can take two approaches: run new experiments designed specifically to find weaknesses or marshall all the data from past experiments. The latter is clearly more efficient as a first step but also very difficult given the current state of experimental economics. Data presented in most papers is not sufficiently detailed or standardized to allow for careful analysis. The process of extracting the information from graphs in journal articles is clumsy and time-consuming. Standardized computer-readable formats would allow faster and easier analysis across experiments and experimenters. For the model above we can extract data on δ, N, pz and M for almost all dilemma experiments[25] (up to the accuracy of the graphs) usually with δ accurate to at most one significant digit).

But the experimentalist should not always wait for the theorist to identify the data and parameters that are important to keep. A standard data interchange format would be an important public good for researchers. Any ideas or volunteers?

3.1 Large numbers

What does the model predict as $N \to \infty$? Since we were unable to sign the effect of a change in N, one might suspect we could say very little. But we get lucky.

The first thing to note is that $F(q) \to 0$ as $N \to \infty$ if $q < \pi N$ and $F(q) \to 1$ if $q > \pi N$. Therefore, $N \to \infty \Rightarrow F(q) \to 0 \; \forall q < \infty$. Therefore $1 - F\left(\frac{1}{M} - 1, \pi, N\right) \to 1$ for all $\pi > 0$. Thus, as $N \to \infty$, $\pi \to \pi^{\infty}$ where

$$\pi^{\infty} = 1 - H\left(pz(1-M)\right).$$

Note that $\pi^{\infty} = 0$ if and only if $H\left(pz(1-M)\right) = 1$ or if and only if $pz(1-M) \geq \bar{V}$, the maximum possible value any agent attributes to being in a successful coalition of contributors.

Also note that if $H(\cdot)$ is shaped like a (truncated) Normal with small variance around V^* then $pz(1-M) > V^* \Rightarrow \pi^{\infty}$ near 0. While $0 < pz(1-M) < V^* \Rightarrow \pi^{\infty}$ much larger. This might help explain some of the

[25] I will try to do this when I have time and a research assistant.

data in Isaac, Walker and Williams [102]. Of course, V^* is estimated and not a controlled variable.

3.2 Asymmetries

What does the model predict about the effect of asymmetric endowments or tastes? The easiest asymmetry to handle occurs when there are variable endowments, z. Suppose $z \sim L(\cdot)$ a c.d.f. I assume for now that z and V are independent and that $L(\cdot)$ and $H(\cdot)$ are common knowledge. Remember a subset $T \subseteq \{1,...,N\}$ is successful under linearity if and only if $\Sigma_T \frac{a}{N}(\Sigma_T M_i) \geq p\Sigma_T M_i$ which is true if and only if $Ta \geq Np$ *no matter what the endowments are.* Thus if i has value V_i and endowment z_i, then i will contribute if and only if

$$\left(\frac{V_i}{z_i}\right) \geq \frac{p(1-M)}{\text{prob }\{\text{number of others contributing} \geq \frac{1}{M}-1\}}$$

Given $H()$ and $L()$ we can compute $I(b)$ the c.d.f. of $\left(\frac{v}{z}\right) = b$. Then

$$\pi = 1 - I\left[\frac{p(1-M)}{\left(1-F\left(\frac{1}{M}-1,\pi,N-1\right)\right)}\right].$$

This is essentially identical to (4) with two differences. First, z is not an exogenous variable, so $\frac{\partial\pi}{\partial z}$ makes no sense. Second, $L(z)$ is controllable by an experimenter.

What do the data say? Well, $L(\cdot)$ has never been controlled although variations in endowments (without common knowledge[26]) have been tried. If each i believed $L(\cdot)$ were the model, what would happen to π? Of course, we need a baseline value of z to compare this to. The natural one is to use $\bar{z} = \int z dL(z)$, the expected value of z. We ask how the π^* that solves

$$\pi = 1 - H\left(\frac{p\bar{z}(1-M)}{1-F\left(\frac{1}{M}-1,\pi\right)}\right)$$

[26] I should check Isaac for this.

compares to the π^{**} that solves

$$\pi = 1 - G\left(\frac{p(1-M)}{1 - F\left(\frac{1}{M} - 1, \pi\right)}\right)$$

We can rewrite these as

$$\pi^* = 1 - H\left[\bar{z} \cdot \delta(\pi^*)\right]$$

and

$$\pi^{**} = 1 - G\left[\delta(\pi^{**})\right]$$

Then we can use a transformation of variables where $y_1 = \frac{v}{z}$ and $y_2 = z$ to derive the c.d.f. of $\frac{v}{z}$ as

$$\begin{aligned} G(q) &= \int_0^q \int_0^\infty h(y_1 y_2) l(y_2) y_2 dy_1 dy_2 \\ &= \int_0^\infty \int_0^q h(y_1 y_2) y_2 dL(y_2) dy_1 \end{aligned}$$

where $h(v)dv = dH(v)$ and $l(z)dz = dL(z)$. We first want to compare $H(\bar{z} \cdot \delta(\pi^*))$ with $G[\delta(\pi^*)]$ or

$$\int_0^\delta \left[\int_0^\infty h(y_1 y_2) y_2 dL(y_2)\right] dy_1$$

with

$$\int_0^\delta \left[h(y_1 \bar{y}_2)\bar{y}_2\right] dy_1$$

where $\bar{y}_2 = \int y_2 dL(y_2)$.

Let $r(x) = xh(y_1 x)$. By Jensen's inequality

$$E(r(x)) < r(E(x)) \text{ if } r(\cdot) \text{ is concave}$$

and

$$E(r(x)) > r(E(x)) \text{ if } r(\cdot) \text{ is convex.}$$

Thus, if $xH(y_1 x)$ is convex in x for all $y_1 > 0$ then $H(\bar{z}\delta(\pi^*)) < G(\delta(\pi^*))$. Therefore, since π^* was a stable point, $\pi^{**} < \pi^*$. Asymmetry in z yields lower expected contributions. If $xh(y_1 x)$ is concave in x, then the effect reverses. Unfortunately, the experimenter does not control $h(\cdot) = \frac{dH}{dv}$. Notice, however, that if H is uniform then $xh(y_1 x) = cy_1 x^2$ which is convex.

Although we have concentrated on asymmetric z we could as easily have analyzed asymmetric p or $p \cdot z$. A slightly more difficult but more interesting case arises when $G(\cdot)$ is non-linear and individuals differentially value public goods. These are the environments studied by Andreoni [4]), Banks, Plott, Porter [8], Isaac, McCue, Plott [94] and Brookshire, Coursey and Redington [24] without controlling for common knowledge. The theory (under asymmetric information) remains to be worked out.

4 Mechanism Design

[To come later]

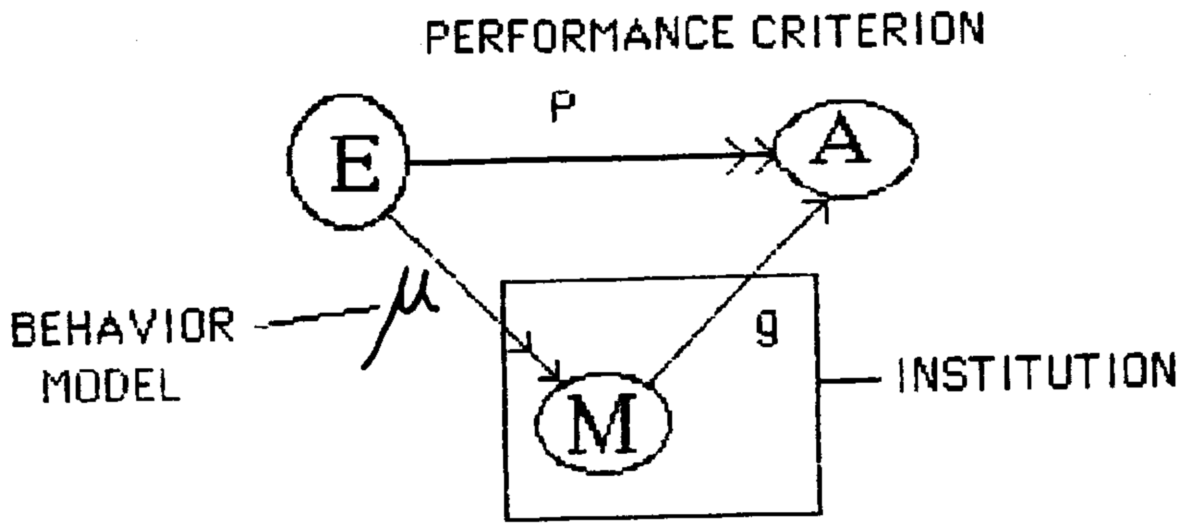
PERFORMANCE CRITERION
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FIGURE #1

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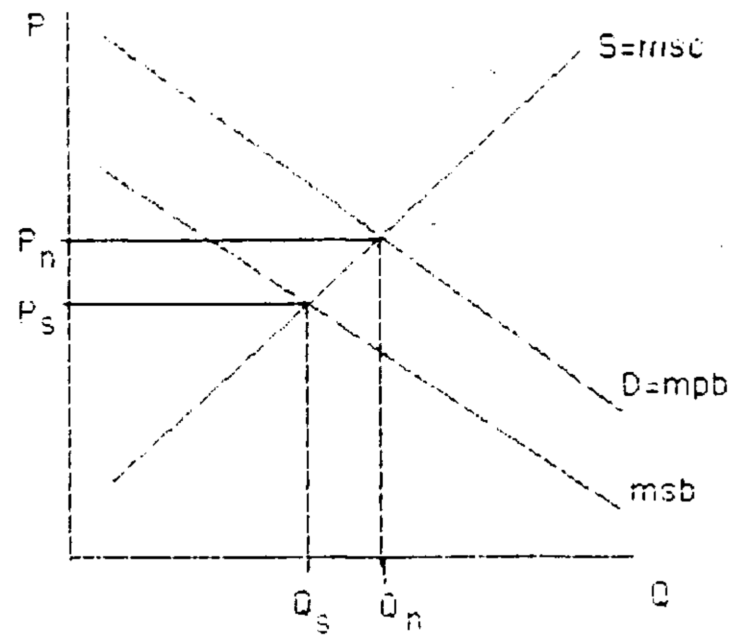

Figure #2

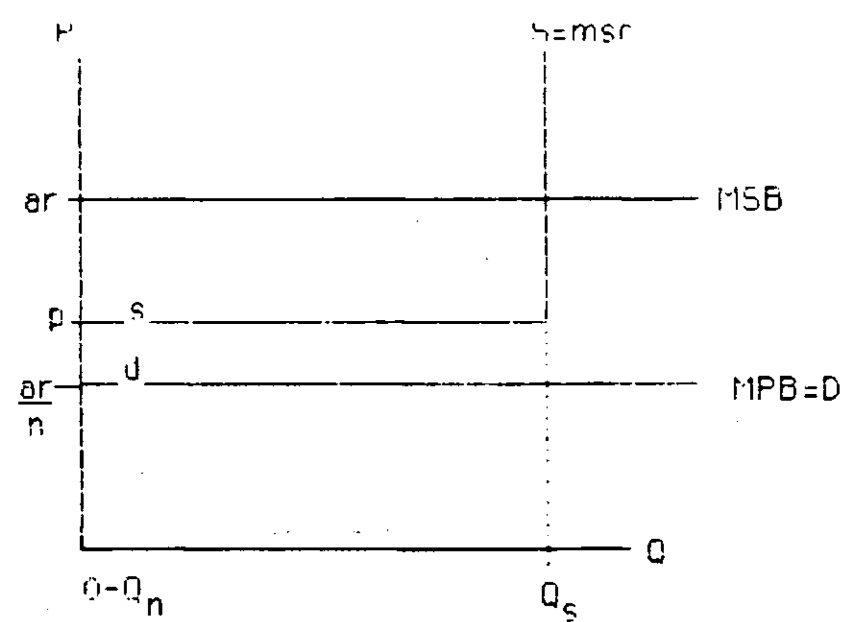

FIGURE #3

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