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PUBLIC GOODS PROVISION IN AN EXPERIMENTAL ENVIRONMENT*

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1. Introduction

The problem of public goods provision has been central to many areas of economics. The traditional economic models, resting on assumptions about nonexcludability and single-period behavior, led directly to a prediction that social decision processes which rely upon voluntary individual payment for the provision of public goods cannot work [see, for example, Feldman (1980)]. According to such models people will not voluntarily pay. Because the profit incentive cannot operate naturally to induce supply in an ordinary market setting, public goods serve as a classic model of market failure and exist as the foundation for many modern theories of government.

The central purpose of the experiments we conducted was to explore the behavior of groups within a set of conditions where we expected the traditional model would work with reasonable accuracy. As will be outlined below, our expectations were confirmed. The experiments and procedures we identify thus provide a setting within which public goods are provided at near zero levels and thus constitute a context for the testing of institutions and theories that are proposed as solutions to the public goods problem. Some potential solutions are explored in this paper and the results are also reported. In addition to serving as a background for further experiments, our results unambiguously demonstrate the existence of the under-provision of public goods and related 'free riding' phenomenon and thereby discredit the

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claims of those who assert as a general proposition that the phenomenon does not or cannot exist. Of course, had our results been the opposite we would have been able to reject a popular model under circumstances which were deliberately chosen to give the model a 'best chance'.

Examples of public goods problems taken from natural settings are, for some scholars, inadequately documented. Johansen, for example, states: 'I do not know of many historical records or other empirical evidence which show convincingly that the problem of correct revelation of preferences has any practical significance' [Johansen (1977, p. 147)]. Experimental results which are frequently decisive in differentiating among models in other areas of economics have been characterized by residual ambiguities about the applicability of the public goods model. Typically, groups in experimental public goods environments do not produce the optimum amount under a system of voluntary contribution, but the quantities produced are usually within 30–50 percent of the optimum, and 60–85 percent of the individuals contribute something. These data are to be compared with the public goods model predictions of a zero level of the public good provision with no one at all paying. Schneider and Pommerehne (1981, p. 702) conclude: 'individuals did systematically behave as free riders ... but the extent to which free riding occurred was not great'.

Three aspects of previous experiements led us to the particular experimental procedures we used. The first is the possible role of repetition and time. Experimental explorations of the public goods model have typically involved only a single period, while many static economic models (such as those of market behavior) are known to be accurate only after the operation of a convergence process within a repeating stationary environment [Plott (1979), Smith (1979)]. Very early experiments suggest that the same phenomenon will hold in the case of public goods. The Fouraker and Siegel (1963) duopolies and triopolies experiments become relevant if price quotations are interpreted as public goods. These exhibit convergence behavior with repetition of periods. Similarly, the externality experiments of Plott (1983) can be interpreted as decision situations involving several public goods. The convergence toward competitive equilibrium of these markets with externalities can be interpreted as a market test of zero provision of the public good as predicted by the public goods model. Thus, one key feature of observed behavior seemed to be the replication of the decision conditions over time.

The second major aspect of other experimental designs was a type of discreteness of public goods which we wished to avoid. In Smith's experiments, for example, the Lindahl equilibrium was five or six units. The discreteness of outcomes as well as the small numbers involved, might induce a type of 'all or none' option which might encourage preference revelation. Third, several of the public goods experiments involved processes other than voluntary contributions and some of the voluntary contributions experiments involved iterative processes of proposals prior to giving a decision. Such iterative processes may have their own important features which help eliminate the public goods problem and so, given our objective, they were to be avoided. Finally, several of the existing experiments included, as part of the instructions, references to naturally occurring situations of a sort which might be bothersome in light of the results.[1]

2. Design, parameters, and process

A total of nine experiments were conducted. A summary of the relevant features of each experiment is contained in table 1. As can be seen, subjects were recruited primarily from undergraduate economics classes at Pasadena City College and the California Institute of Technology. The single exception is experiment 7 in which subjects were recruited from an undergraduate sociology class at Pasadena City College. This was an attempt to check a hypothesis advanced by sociologists that 'free riding' only occurs in societies populated by economists [Marwell and Ames (1981)].

The experiments were conducted in a classroom with subjects seated to allow as much space as possible between them. The instructions (see appendix) were read. After taking the 'test' and answering questions, the experimenter then began the experiment which lasted about an hour.

Subjects were guaranteed a minimum of $5.00 for participating. Before the instructions were read, subjects were endowed with the $5.00 and told that all earnings in the experiment would be paid in addition to that initial amount. Values for the public goods were induced through the application of induced value theory [Smith (1976), Plott (1979)]. Each subject was assigned one of the two payoff conditions in fig. 1 (which indicates payoff as a function of the level of public goods provided in any given period). These conditions, called 'high' and 'low' payoff condition, are approximated by the functions in the figure. The earnings of a subject in a period was the individual's payoff as determined by the level of public good provided that period and the individual's payoff chart minus the amount the individual contributed toward the provision of the public good that period. Thus, the total earnings of an individual during the experiment was the initial payment guarantee plus the sum over all periods of the earnings for each period.

As indicated in table 1 there were ten subjects in each experiment (except experiments 4 and 9) half of which had the high payoff condition and the other half had the low payoff condition. The public good was supplied at a constant marginal cost of $1.30. *Optimum quantities* can be found by equating the vertical summation of individual valuations (payoffs) to the marginal cost. As shown in fig. 2, this yields any quantity in the half open interval

[1] In the Schneider and Pommerehne study, for example, the subjects were students and the public good was the purchase of the professor's forthcoming book.

Table 1

Experiment	Subject pool[a]	Number of subjects in payoff condition		Lindahl			Nature of intervention	Comment
		High	Low	Quantity	Price ($) for high condition	Price ($) for low condition		
1	C.I.T. Undergraduate Economics	5	5	(23, 24]	0.176	0.084	6th period on Lindahl prices known	(E = MI)[b]
2	C.I.T. Undergraduate Economics	5	5	(23, 24]	0.176	0.084	10th period on communication allowed	(E = KM)[b]
3	P.C.C. Undergraduate Economics	5	5	(23, 24]	0.176	0.084	6th period on Lindahl prices known	(E = MI)[b]
4	P.C.C. Undergraduate Economics	5	4	23.04	0.186	0.0918	7th period on communication allowed	(E = MI)[b]
5	C.I.T. Undergraduate Economics	5	5	(23, 24]	0.176	0.084		(E = WR)[b] An individual violated rules and experiment terminated

6	C.I.T. Undergraduate Economics	5	5	(23, 24]	0.176	0.084		(E = CL)[b] Two subjects were very confused
7	P.C.C. Undergraduate Sociology	5	5	(23, 24]	0.176	0.084	8th period on communication allowed	(E = MI)[b]
8	C.I.T. Undergraduate Economics	5	5	(23, 24]	0.176	0.084		(E = MI)[b]
9	C.I.T. Undergraduate Economics	4	4	20.6	0.214	0.111	7th period on slightly incorrect Lindahl prices known	(E = WR)[b] 8 rather than 10 subjects caused some problems

[a]C.I.T. = California Institute of Technology.
P.C.C. = Pasadena City College.
[b]E = Initials of experimenter: MI = Mark Isaac; CL = Carl Lydick; KM = Kenneth McCue; WR = William Rogerson.

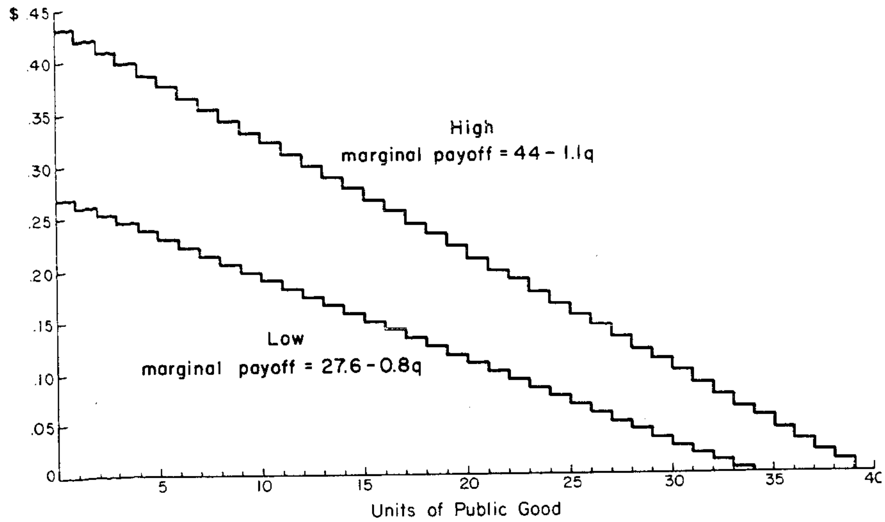

Fig. 1. Derived demand curves for high and low payoffs.

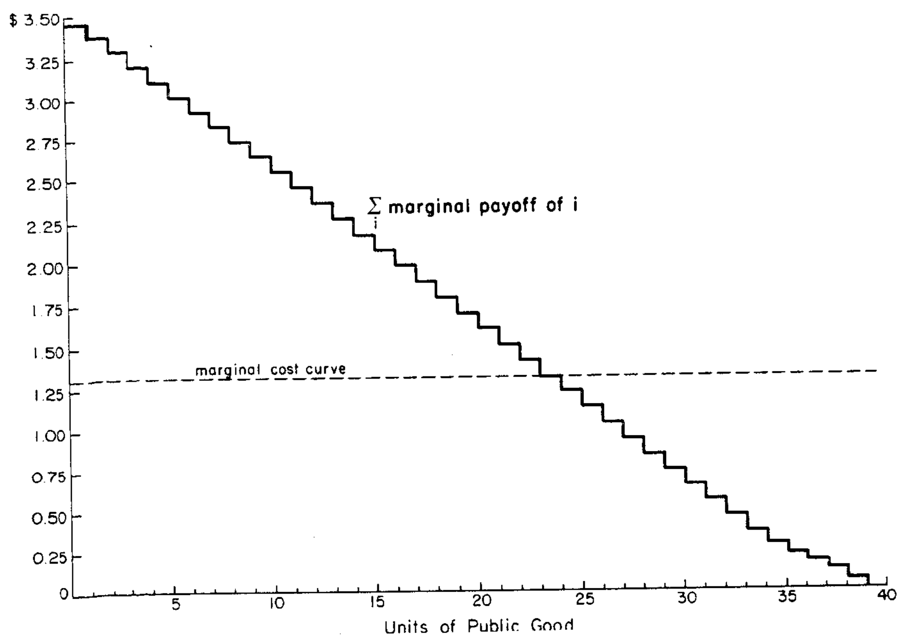

Fig. 2. Market demand and marginal cost curve.

(23, 24]. At 24 units the *Lindahl contribution* is \$4.22 (\$0.176 per unit) for those in the high payoff condition and \$2.02 (\$0.084 per unit) for those in the low. For experiments 4 and 9 these quantities are different, as shown in table 1.

The decision process for the primary voluntary contributions process proceeds as follows. At the beginning of a period each subject privately wrote on a slip of paper the amount (s)he wished to contribute to the jointly provided public good that period. The paper was collected by the experimenter. The sum of these contributions by the subjects was calculated by the experimenter and was divided by the (constant) cost of the units to obtain the level of the project funded. The level of the project thus funded was announced and used to determine each individual subject's monetary payoff from the payoff chart. This payoff determination was made privately by each individual. The subjects recorded the payoff amount on a form provided as a part of the instructions. The earnings for a subject were calculated as the difference between the monetary payoff determined by the level of the public good and the contribution made by the subject for the provision of the good. A brief period was allowed for the computation of this profit before the next period began.

There were two standard rules regarding the information of participants: first, the subjects were not allowed to communicate with one another during the experiment. Secondly, the individuals had no knowledge about the nature of any payoff charts other than their own. In a technical sense it was *public* information that no one had information about other subject preferences. Furthermore, it was public information that the final period was known with certainty to no one. Because of previous indications that communication could be an important treatment variable [Dawes et al. (1977)], these general rules regarding information were altered at certain points in the experiments (see table 1). Lindahl optimal contributions were individually disclosed to the subjects after the fifth, fifth, and sixth periods in experiments 1, 3, and 9, respectively.[2] Experiment 9 was conducted with eight rather than the planned ten subjects and the experimenter revealed the slightly incorrect prices which had been calculated for ten persons. In experiments 2, 4, and 7, communication was allowed after the ninth, sixth, and seventh periods, respectively.[3]

[2]The procedure for announcing the Lindahl equilibrium values was as follows: each participant was given a slip of paper with a number (the Lindahl contribution for that individual) on it. The group was told: 'If each of you were to expend the amount that each saw on the slip of paper, then twenty-four units would be produced.' Unfortunately, it was discovered in experiment 1 that at least one subject understood the experimenter to be saying that this optimal level was a required level of contribution. After the misunderstanding in experiment 1, the experimenter in other experiments where the Lindahl prices were disclosed emphasized that it was not a requirement that they contribute the Lindahl value.

[3]The subjects were told before the period began that they were free to discuss any aspect of the experiment (or any other subject for that matter), provided that they did not discuss the dollar amounts of individual payoffs or the dollar amount they had contributed in past periods.

3. Results

The results are discussed in three subsections. The first two reflect different levels of data aggregation. The third is an analysis of the effects of experimenter interventions to change the rules and other parameter changes.

3.1. Public good provision

In our reporting of aggregate data we used only those experimental periods for which no change in rules had been made. Additionally, in experiments 5 and 6 events occurred such that in our opinion they were made noncomparable with the other experiments in our series.[4] As such, in our aggregate data we report only the results of the remaining experiments: 1 through 4, and 7 through 9.

The time series for each experiment is shown in fig. 3 and table 2, where we show the quantity of public good provided in each period of each experiment. The conclusions listed below simply make precise the visual impression that levels of public good provision are low, but nonzero and decrease with time.

Conclusion 1. By the fifth period the Lindahl equilibrium can be rejected in favor of the public goods model as can any other model which predicts that the level of public goods provision will be 'substantially above' zero.

By period 5 the average number of units provided in the seven experiments is 2.1 units which is 8.8 percent of the 24-unit Lindahl optimum. In five of the seven last periods the provision level is one unit or less. However, the

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Qualitative descriptors (such as a great deal, much, etc.) were allowed. [It might be interesting to note here that Chamberlin's (1978) subjects also participated in a second decision in which communication was allowed, but he placed no restrictions on the conversation, except that the previous level of contribution could not be revealed.]

[4]In experiment 6 it was discovered, after the experiment had been run, that two subjects misunderstood the instructions completely, leading them to submit expenditures for the public good which were entirely different from the expenditures they were recording on their individual forms. Thus the experiment as a whole was contaminated. In experiment 5 a different event occurred. In the first two periods the participants purchased 6.5 and 7.6 units, respectively; this was not out of line with the results from the other seven experiments (excluding experiment 6). However, in period 3, 27.5 units (greater than the social optimum) were reported purchased, and 22.5 units were reported purchased in period 4. The jump was caused exclusively by participant number 10 who 'contributed' $30, insuring himself of a loss of over $25, far above the original $5 endowment. A one-time loss was not unique per se (in experiment 7 in the first period several participants insured themselves of losses of over three dollars), but insuring oneself of a loss after the first period was unique to this experiment. In particular, when the same individual followed his $25 loss with a new contribution of $20 (insuring a loss of over $15), the experiment was terminated. The subject in question departed immediately without leaving his name or contributing to the necessary bookkeeping and owing the experimenter over $40. For this reason, we have not included data from experiment 5 in any of our aggregates, though, as with experiment 6, the individual data will be used to explicate some aspects of our results below.

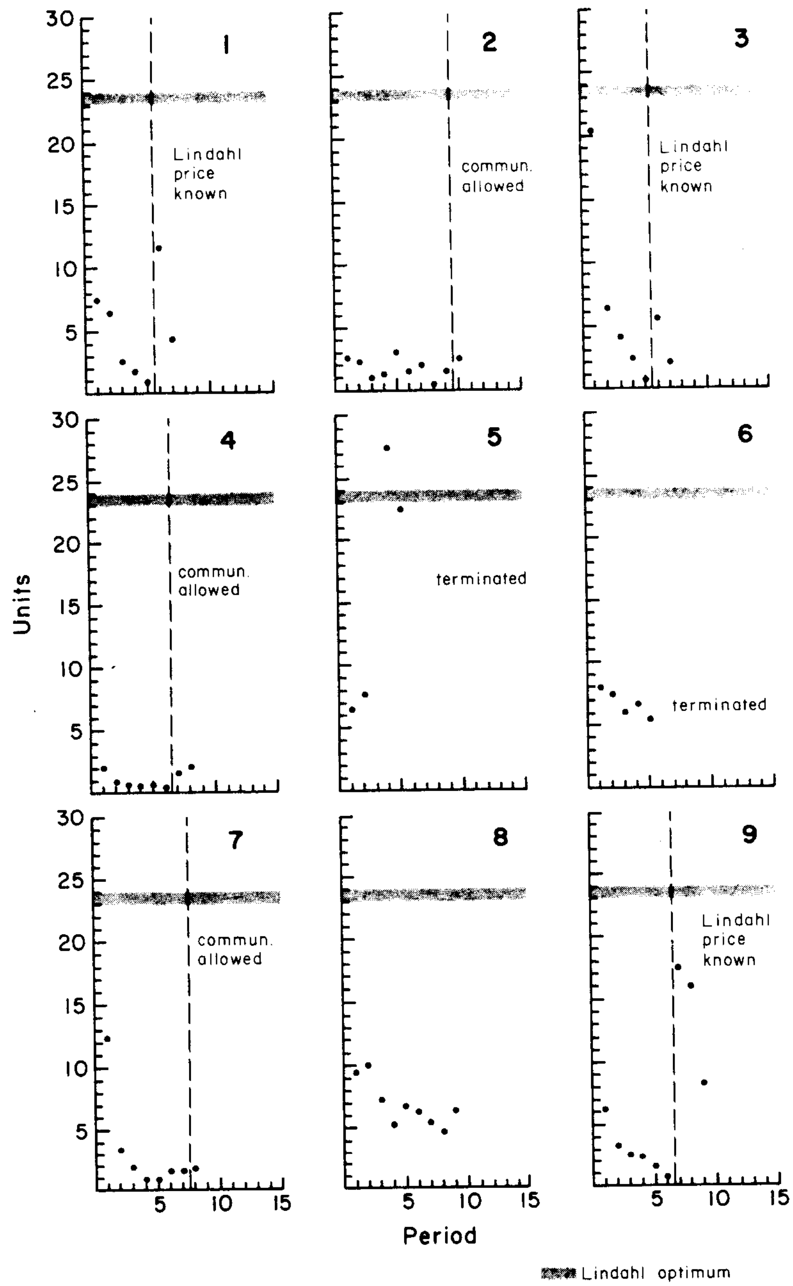

Fig. 3. Units provided, by period.

Table 2
Total units funded, efficiency, and variance of individual contributions for all experiments.

Experiment	Variable	Period 1	2	3	4	5	6	7	8	9	10
							Lindahl prices known				
1	Units	7.6	6.2	2.7	1.9	1.0	11.8	4.2			
	Efficiency (%)	52	44	20	15	8	72	31			
	Variance	1907	1461	291	205	57	5093	796			
											Communication allowed
2	Units	2.8	2.2	1.0	1.2	3.0	1.4	2.2	0.5	1.6	2.4
	Efficiency (%)	21	17	7	10	23	11	17	4	13	19
	Variance	307	125	31	139	913	65	416	12	234	150
							Lindahl prices known				
3	Units	20.5	6.3	4.0	2.2	0.9	5.6	2.0	0.6		
	Efficiency (%)	95	45	30	17	7	41	16	5		
	Variance	17429	1434	727	415	38	2101	405	17		
								Communication allowed			
4	Units	2.1	1.0	0.8	0.5	0.7	0.3	1.7	2.0		
	Efficiency (%)	17	8	7	4	6	2	10	12		
	Variance	187	37	27	11	29	3	109	155		

5	Units	6.5	7.6	27.5	22.5	Terminated				
	Efficiency (%)	46	52							
	Variance	1419	1825	90560	2341					
6	Units	7.9	7.4	6.0	6.7	5.6	Terminated			
	Efficiency (%)	54								
	Variance	1384	1289	1183	975	831				
7									Communication allowed	
	Units	12.7	3.4	2.1	1.0	1.0	1.8	1.8	1.9	
	Efficiency (%)	76	26	16	8	8	14	15	15	
	Variance	10847	431	163	39	41	137	138	138	
8	Units	9.3	10.2	7.3	5.3	6.1	6.1	5.5	4.8	6.5
	Efficiency (%)	61	66	51	39	47	43	40	35	46
	Variance	2118	2257	1147	681	1124	1177	1210	1719	1927
9								Lindahl prices known		
	Units	6.3	3.2	2.6	2.4	1.6	0.9	17.7	16.0	8.2
	Efficiency (%)	51	28	23	22	15	8	95	92	62
	Variance	1308	640	473	323	208	56	8338	6959	4139
Average	Units	8.8	4.6	2.9	2.1	2.1				
Average	Efficiency (%)	53	33	22	16	16				
Total	Variance	28850	3586	1087	572	1140				

range of the observations as opposed to the mean privides the easiest way to give conclusion 1 some context. Any mode of public goods provision which has a median prediction of more than 6.6 units or 27 percent of the Lindahl optimum will be rejected (at the 0.0078 level of confidence) in favor of the alternative that the level is 6.6 units or below. All observations lie at 6.6 units or below so the appropriate statistic is obtained (seven of seven) from the binomial distribution. Models for which the median prediction is more than three units (12.5 percent of the Lindahl optimum) will be rejected at the 0.0547 level in favor of the alternative that the median is in the interval [0, 3]. Thus, models which predict substantial levels of public goods can be rejected if 'substantial' is understood to be on the order of 13–28 percent or more of the Lindahl optimum.

Conclusion 2. Funding levels are near zero but still above zero.

In period 5 the lowest level of public goods provision observed was 0.7 units. All other observations were above this. Any model which predicts that the median observed level provided is less than 0.7 units will be rejected at the 0.0078 level of significance. This suggests that the error in the public goods model is possibly a variable of interest to public finance. The error term of the model which predicts zero contributions can only be positive (people cannot contribute negative qualities) and so the error will exist any time any individual contributes anything at all. As will be indicated below, people experiment with making contributions possibly in hope than others will follow. Such 'errors' in the model if better understood might themselves suggest sources of public revenues, even though small in relation to the optimum.

Conclusion 3. With replication the level of public goods provision falls.

Both the graphs in fig. 4 and table 1 demonstrate this phenomenon. The average quantity of the public good provided begins at 8.8 units and falls to 2.1 units by period 4. In all experiments 40 changes were observed between periods with no experimenter intervention and, of these, 30 were changes downward (equal probability of movement rejected at 0.01). Rank order tests from the period of highest provision to the lowest correlate highly with the period number in all experiments except experiment 2 which began with a relatively low level of provision and stayed there.

Conclusion 4. The first three conclusions hold if system efficiency is used as a measure of the level of public goods provision in place of the number of units.

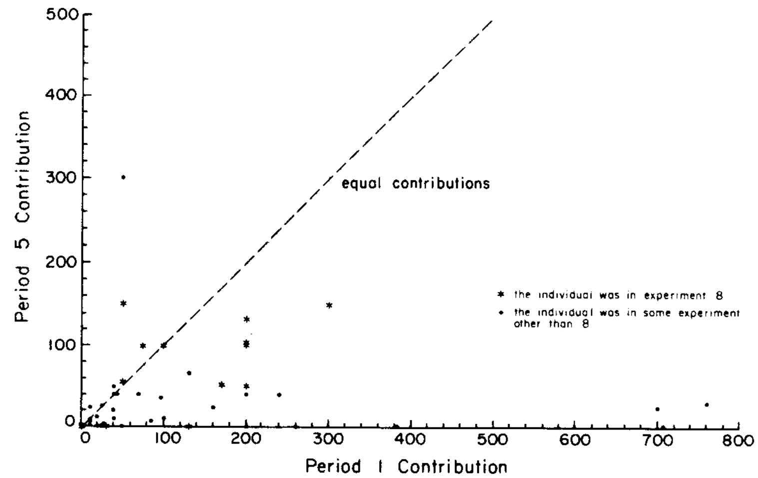

Fig. 4. Individual behavior in first and fifth periods in experiments 1, 2, 3, 4, 7, and 8.

The system should be 100 percent efficient at the Lindahl equilibrium and 0 percent efficient at the public goods model equilibrium of 0 units. As shown in table 1, an almost one-to-one relationship exists between units provided and efficiency. This is not surprising since there is a functional relationship between units provided and efficiency.[5] For a ten-person experiment, efficiency increases (though in a decreasing fashion) as a function of units provided on $(0,23]$, is constant on $(23,24]$ and decreases for values greater than 24.

3.2. *Individual decisions*

In our design the single-period dominant strategy for an individual is to

[5]The exact functional relation ship between units provided and efficiency may be calculated as follows. Let x be the units provided in a period ($x=\sum c_i/130$, where c_i is the contribution of individual i). Then an individual's gain, if he has a linear marginal payoff function a_i-b_ix, is

$$\int_0^x (a_i-b_iz)\,\mathrm{d}z-c_i=a_ix-\frac{b_ix^2}{2}-c_i.$$

For a ten-person experiment with five individuals having demand curves of $44-1.1x$ and five having $27.6-0.8x$, we have that total gains equals

$$5\left(44x-\frac{1.1x^2}{2}\right)+5\left(27.6x-\frac{0.8x^2}{2}\right)-\sum c_i.$$

Now, $\sum c_i=130x$, so the sum of the gains is simply

$$228x-4.75x^2.$$

To find the efficiency, divide this by the maximum gain possible (evaluate the above at $x=24$). Now, as we have a 'stepped' demand curve, the actual formula will be altered slightly to take this into account. Notice that efficiency depends only upon the number of units provided.

contribute nothing to the provision of the public good. The Lindahl equilibrium contributions are \$4.22 per period and \$2.10 per period for individuals in the high and low payoff configurations, respectively. Natural questions are related to the proportion of the subjects who followed one or the other strategy.

Conclusion 5. Very few individuals contributed nothing the first period, but the proportion of individuals who contributed small amounts increases with replication.

Fig. 4 is a graph of for individual contributions in periods 1 and 5. Along the horizontal axis is measured the period 1 contribution. The vertical axis measures period 5 contributions. Thus, a point at (125,2) indicates that one individual's contribution was \$1.25 in period 1 and \$0.02 in period 5. Notice that 13 individuals of the 67 individuals in the seven full experiments contributed 0 in period 1 but 25 of the 67 contributed 0 in period 5 and another 7 only contributed \$0.01. Only one individual who contributed 0 in period 1 contributed a positive amount (\$0.01) in period 5.

As is evident from the figure, the contributions of nearly all subjects reduced between the two periods. Of the 54 subjects who made nonzero contributions in period 1, 44 reduced their payment, while only 7 increased the payment, and 4 of these 7 were in experiment 8. This has the effect of the distribution moving to the right (below the line) and 'piling up' at contributions near zero. The only exceptions to the downward movement are the numbers from experiment 8 (separately marked in the figure) in which both individual decisions and the aggregate behavior was somewhat different from the others.

Conclusion 6. Period 1 decisions are uncorrelated with later decisions.

Table 3 contains the correlation coefficients of individual period-to-period contributions. As can be seen, period 1 contributions are significantly correlated with period 2's but not with any other period. Similarly, period 2 contributions are correlated (0.70) with period 3's but these are also correlated with all following decisions. Period 1 decisions are thus different from those of later periods, individually and as a group.

Conclusion 7. Individuals in the high payoff condition contribute more than individuals in the low payoff condition.

Average contributions by payoff condition are contained in table 4. These quantities are also shown as a percentage of the Lindahl equilibrium quantities. A difference in means tests on quantities ($t=2.2$, 3.0, 2.2, 6.8, and

Table 3
Interperiod correlations for individual expenditures.

Period	1	2	3	4	5	6
	$n=(67)$	(67)	(67)	(67)	(67)	(47)
	1.00	0.32[a]	0.22	0.18	0.06	0.15
		1.00	0.70[b]	0.48[b]	0.40[b]	0.67[b]
			1.00	0.69[b]	0.46[b]	0.70[b]
				1.00	0.62[b]	0.63[b]
					1.00	0.50[b]
						1.00

[a]Significant to less than 0.01.
[b]Significant to less than 0.001.

Table 4
Average individual contribution by payoff condition: In cents and as a percent of Lindahl equilibrium (in parentheses).

Period	1	2	3	4	5
Low payoff	83(40)	47(23)	31(15)	14(7)	16(7)
High payoff	153(36)	79(19)	49(12)	42(10)	42(10)

4.2 for periods 1, 2, 3, 4, and 5, respectively)[6] indicates that individuals in the high payoff group tend to contribute more each period. The conclusion is not true, however, for contributions taken as a percentage of the Lindahl optimum ($t=0.1$, 0.5, 0.6, 0.8, and 0.4 for periods 1, 2, 3, 4, and 5, respectively).

The overall picture is one of convergence to the one-period dominant strategy. Nevertheless the following conjecture is in order:

Conjecture 1. Individual contributions are characterized by occasional attempts to get others to cooperate by unilateral increases in contribution. These attempts are important in explaining the levels of public goods that are produced.

The clearest view of this idea can be obtained by studying those individuals who used the one-period dominant strategy of no contribution at least once during periods of no experimenter intervention. Presumably such individuals have demonstrated an understanding of the strategic structure of the situation. Of these 36 subjects who made a zero contribution, 15 contributed nothing once they had made a zero contribution, but another 17 made subsequent one-period contributions of $0.10 or more and 8 made subsequent one-period contributions of $0.50 or more. The overall im-

[6]Significance levels are: 0.14, 0.09, 0.14, 0.01, and 0.04.

portance of such 'pulses' is that they appear to account for a substantial portion of all contributions. In all nonterminated experiments 38 periods exist after removing all first periods and all periods after experimenter intervention. In about half (16) of those periods the largest contribution was made by an individual whose contribution was larger than that of the previous period and 14 of these surpassed the previous contribution by \$0.50 or more (to be compared to an average nondecrease of \$0.15 in these periods).

While we know of no formal theory of pulses, their occurrence is not unlike Axelrod's (1981) concept of the 'invasion' of an equilibrium by 'mutant' behavior. His finding that a 'cheating' (or 'defecting') equilibrium cannot be 'successfully invaded' by a *single* individual attempting a noncheating strategy is consistent with our finding that the pulses do not, in general, prevent the continued decay of contributions.

3.3. Interventions: Changes in institutions and information

Two different types of procedural changes were studied. One involved informing subjects about the Lindahl equilibrium. The second involved a relaxation of the rules against conversation. In addition, two failures in experimental control allow us to study some effects of unanticipated events.

The location of the Lindahl equilibrium was disclosed on the hypothesis that optimal quantities would be more likely if individuals more fully understood the potential advantages of cooperation. Prior to the sixth period in experiments 1 and 3, and prior to the seventh period in experiment 9, each individual was given a slip of paper which contained that individual's Lindahl equilibrium contribution. The group was then told 'if each of you were to expend the amount of money that each saw on the slip of paper, then twenty-four units would be produced'.

Conclusion 8. Announcing the Lindahl equilibrium quantities and prices causes an increase in the amount of the public good supplied but the higher level does not seem to be stable.

Initially the amount provided increases dramatically in all three experiments (from 1.0 to 11.8 in experiment 1; 0.9 to 5.6 units in experiment 3; and 0.9 to 17.7 units in experiment 9). In the three experiments, 28 individuals each made a decision in each period. In the period before the announcement four decisions of the 28 involved an increase in contribution (11 were decreases) and 15 increased the contribution after the announcement (3 decreased). The hypothesis that the probability of an increase is the same in two periods can be rejected at the 0.005 level ($\chi^2(1)=9.6$). In all three experiments there is an almost equally dramatic decline in the provision of the public good in periods following the first post-disclosure period (from 11.8 to 4.2 units in experiment 1; 5.6 to 2 units in experiment 3; and 17.7 to 8.2 units after two periods in experiment 9). Comparing each individual's contribution in the period of the announcement with that in the last period of the experiment, we find 4 of the 28 increased and 12 decreased. The hypothesis of equal probability of upward and downward movement, given that movement exists,[7] can be rejected at the 0.0278 level of significance. Thus, we are providing evidence that the Lindahl equilibria will not be stable under these procedures.

The second change in procedures involved the subject's ability to communicate. In experiments 2 (period 10), 4 (period 7) and 7 (period 8) subjects were told that they were free to discuss any aspect of the experiment or any other subject, provided that they did not discuss the dollar amounts of individual payoffs, the dollar amounts they had contributed in past periods, or anything amounting to a side payment. Qualitative descriptors (such as a great deal, much, more, etc.) were allowed. This variable has been previously investigated by Chamberlin (1978) and Dawes et al. (1977).

Conclusion 9. Communication increases the level of contribution (and efficiencies). The increase is small but it appears to be stable.

The increase occurs in all three experiments (from 1.6 to 2.4 units in experiment 2; from 0.3 to 1.7 units in experiment 4; and from 1.8 to 1.9 units in experiment 7) but relative to the Lindahl quantity or relative to the increases which resulted from announcing the Lindahl quantities, the increases are small. Of the 29 individuals, 9 increased contributions in the period before conversation (7 decreased) and 19 increased contribution after conversation (4 decreased). The hypothesis of equal probability of upward movement can be rejected at the 0.07 level of confidence ($\chi^2(1)=3.52$). Interestingly enough, in experiment 4 the amounts contributed do not fall in the second period as they did when the Lindahl quantities were announced. In fact, the number of units provided goes up. Of the 9 individuals who made a second decision after full communication was allowed, 4 increased and 1 decreased, so certainly statements that the movement upon replication is downward receive no support.

There were two experiments in our series in which events occurred that may provide some insight into several aspects of the problem of funding a public good. In experiment 5 one subject in effect provided by himself 23 units of the public good in period 3. Period 3 was the first period in which our 'altruist' provided by himself 23 units of the public good so period 4 was the first period in which the other participants in the experiment could react to the generosity of the previous period (they had no way of knowing the

[7]Nine of the twelve for which no movement occurred were contributing $0.01 or less.

cause of this generosity or who was responsible for it). One natural question to ask in this instance is whether others responded to this large increase by increasing their own contribution. The answer is:

Conclusion 10. Unilateral altruism by one individual did not appear to increase the contribution of others.

Of the 9 remaining participants, 2 increased and 3 lowered their level of contribution from period 3 (reject the null hypothesis that the probability of an increase is 0.5 at the 0.07 level of significance). The conclusion must be qualified, however, because the two individuals who did increase their contribution did so by a relatively large magnitude. Both increases were over $1.50 which exceeds all increases in all experiments in all periods in which no experimenter intervention occurred.

The other experiment in which the planned procedures went astray was experiment 8. In that experiment (which also differed from the others in the fact that it was the only experiment in which a moderate level of the public good continued to be provided through the first five periods), after individual expenditures had been collected and the total announced to the group for period 6, one individual informed the group that his expenditure had not been collected. His expenditure was then duly collected, added to the total, and the total announced. Since the individual's contribution was zero, the total announced was the same as the previously announced total. Two subjects of the remaining 9 reduced their contribution the period after the discolosure, 2 increased the contribution, and the other 5 did not change. Thus:

Conclusion 11. The disclosure of a zero level of contribution by one of the participants appears to have had only marginal effects if any at all.

4. Concluding remarks

Voluntary contribution systems seem to be most effective if only a single (one-period) contribution is required. Previous experiments with varying types of processes yield public goods levels from 35 percent to 70 percent of the Lindahl optimum. Similarly, in our experiments the first period yielded an average of 38 percent of the optimum quantity. We are not convinced that percent of optimum is the best (or even proper) measure to apply in the investigation of public goods problems. Nevertheless, it is the primary tool available now and measures in the range of those we report have caused several authors to express substantial optimism about the potential for voluntary public finance: 'certainly the clearest, and perhaps the most important, finding in [the] study is the lack of support for the strong free-rider hypothesis' [Marwell and Ames (1979, p. 1349)]; 'Subjects persist in investing substantial portions of their resources in public goods despite conditions specifically designed to maximize the advantage of free riding and thus minimize investment' [Marwell and Ames (1980, p. 937)]; 'there is only modest evidence for free riding as compared with the importance attributed to it in the literature' [Schneider and Pommerehne (1981, p. 702)].

Our results suggests that this optimism is unwarranted for cases in which contributions must be obtained repeatedly over time. Contributions quickly erode to low levels after two or so periods. Furthermore, the tendency for the erosion of contributions is not unique to societies populated by economists, as some sociologists have suggested [Marwell and Ames (1979)]. Our single experiment 7 with sociology subjects yielded substantially the same results as other subject pools, including economists. After a few replication no model of which we are aware is more accurate than the single-period dominant strategy Nash equilibrium.

Our finding that replication tends to exacerbate the use of a one-period dominant strategy runs counter to a common thread of intuitions one develops from recent theoretical investigations of repeated games. See, for example, Friedman (1977), Kurz (1978), Smale (1980), Axelrod (1981), and Kreps, Milgrom, Roberts and Wilson (1982). Indeed, the natural principles to apply are those of a repeated game with imperfect information but, as they are currently developed in the literature, we do not see how to apply them consistently to describe the major empirical regularities. It seems as though individuals begin to cooperate as might be expected in a 'tit-for-tat' strategy. The 'defection' observed with replication of periods might be described as an effort to learn about the other participants and see if others will fail to retaliate when faced with defection. Subsequent periods can then be described as uncoordinated attempts to 'punish' or to signal a 'new willingness to cooperate' or play 'tit-for-tat'. Success with such attempts would be difficult because the information structure, the report of aggregates rather than individual actions, and the relatively large (10) number of individuals makes individual action difficult, if not impossible, to detect. The announcement of the Lindahl equilibrium should have put the system on a cooperative path if participants were attempting to develop a cooperative equilibrium. The fact that cooperation was not sustained might be explained as 'end play' or, alternatively, as phenomena connected with the 'large' number of participants. The latter explanation is consistent with the oligopoly experiments of Stoecker (1980) who finds that substantial cooperation among 'experienced' oligopolists is not maintained with large (three to five) numbers of participants. The need for a systematic investigation of processes in which substantial communication is possible is suggested by the dynamic game analysis. Perhaps the articulation of threats and strategies that can occur with full communications and are meaningful in the dynamic setting contributed to the cooperative 'stability' we might have observed under those conditions. Communication may, in a sense, enable individuals to more rapidly develop the 'reduced form' that properly connects their actions with the reaction of others.

We do not see constant behavior of all participants over time so it is difficult to claim that we are observing a dynamic equilibrium. But, on the other hand, we have no idea about the amount or type of 'noise' or 'random behavior' that might characterize an equilibrium. So, in spite of conclusion 2 we may have observed a one-period dominant strategy equilibrium — or as 'close' as one might ever get to one, given possible idiosyncratic elements of choice behavior, fundamental limitations to measurement, etc.

We are able to provide a few conjectures about possible improvements in methods for voluntary provision. First, high demanders tend to pay more. The propensity to pay as a percent of the Lindahl optimum is about the same across demanders, so a strategy which diverts fund-raising efforts toward high demanders may make sense. Secondly, the announcement effect of a Lindahl equilibrium seems to be large but unstable, while a process that allows individuals to communicate openly about the process seems to stabilize upward contributions. Thus, we conjecture that a combined approach might be more successful than either taken alone. The data seem to support this idea but we have no ideas based on theory.

Appendix: Instructions

You are about to participate in a decision process in which one of numerous competing alternatives will be chosen. This is part of a study intended to provide insight into certain features of decision processes. The instructions are simple. If you follow them carefully and make good decisions, you might earn a considerable amount of money. You will be paid in cash.

This decision process will proceed as a series of periods or days during which a project level will be determined and financed. The 'level' can be at zero 'units' or more, the exact level of which must be determined. Attached to the instructions you will find a sheet which describes the value to you of decisions made during the process, called the Redemption Value Sheet. *You are not to reveal this information to anyone.* It is your own private information.

During each period a level of the project will be determined. For the first unit provided during a period you will receive the amount listed in row 1 of the Redemption Value Sheet. If a second unit is also provided during the period, you will receive the additional amount listed in row 2 of the Redemption Value Sheet. If a third unit is provided, you will receive, in addition to the two previous amounts, the amount listed in row 3, etc. As you can see, your individual total payment is computed as a sum of the redemption values of specific units. (These totals of redemption values are tabulated for your convenience on the right-hand side of the page.)

The earnings each period, which are yours to keep, are the differences between the total of redemption values of units of the project and your individual expenditures on the project. Suppose, for example, your Redemption Value Sheet was as below and two units were provided.

Redemption Value Sheet

Project level (units)	Redemption value of specific units	Total redemption value of all units
1	600	600
2	500	1100
3	400	1500

Your redemption value for the two units would be 1100 and your earnings would be computed by subtracting your individual expenditures from this amount. If 2.5 units were provided, the redemption value would be determined by the redemption values of the first and second unit plus one-half of the third unit, that is:

$$600+500+(0.5)\,400=1300.$$

The process by which the level of the project is decided will proceed as follows. The number of units of the project is determined by the total expenditures made by individuals. Each unit of the project costs ________. The number of units provided is the total of individual expenditures divided by the cost per unit.

At the beginning of each period you are to write on the Expenditure Form the amount you will spend individually. This number should also be recorded on row 2 of your Individual Record of Earnings. These will be collected and totaled to obtain the total expenditures, which, when divided by the cost per unit, gives the total units provided. During this process you are not to speak to anyone or otherwise attempt to communicate. The total will be announced. The number of units of the period will then be computed and announced.

When the level of project is announced, you should enter the Total Redemption Value of all units obtained from the Redemption Value Sheet on row 1 of your Individual Record of Earnings. You should then subtract row 2 from row 1 on this record to determine you earnings for the period.

Are there any questions?

EXPENDITURE FORM

Individual ______________________

Period ______________________

Expenditure for Project ______________________

Questions (administered after instructions)

1. True or false. My earnings per period are the difference between the total of redemption values for the units of the project determined less the project cost per unit:________.
2. For the ninth unit of the project, the additional redemption value for that specific unit is________.

My total of redemption values for all units for a project of size 3 units is________; for a project of size 17.5 units is________; for a project of size 38.1 units is________.

No.________

INDIVIDUAL RECORD OF EARNINGS

	Period						
	1	2	3	4		19	20
Redemption Value: Total for All units Provided					...		
Individual Expenditure							
Per Period Earnings							

REDEMPTION VALUES

Project Level (Units)	Redemption Value of Specific Units (cents)	Total Redemption Value of all Units (cents)
1	42.9	42.9
2	41.8	84.7

3	40.7	125.4
4	39.6	165.0
5	38.5	203.5
⋮	⋮	⋮
36	4.4	851.4
37	3.3	854.7
38	2.2	856.9
39	1.1	858.0
40	0.0	858.0

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