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Voluntary provision of threshold public goods with continuous contributions: experimental evidence

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Abstract

This paper examines experimentally the effects of allowing individuals to contribute any desired proportion of their endowments toward a threshold public good. Permitting continuous rather than binary ''all-or-nothing'' contributions significantly increases contributions and facilitates provision. A money-back guarantee further encourages provision, especially when the threshold is high. A high threshold discourages provision in the absence, but not in the presence of a money-back guarantee. High rewards also significantly increase contributions and provision. Sufficiently high rewards elicit convergence of contributions to the threshold, rather than the deterioration towards free riding, often reported in previous studies.

Keywords: Threshold public goods; Voluntary provision; Continuous contributions

JEL classification: H41; C92

1. Introduction

This paper examines experimentally the effects of allowing individuals to contribute any desired proportion of their endowments toward a threshold public good. In a standard threshold public goods game, each member of a group is asked to make a private contribution toward the production of the public good. If enough contributions are made to reach the stated threshold level of contributions, the

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good is provided. If insufficient contributions are made, the contributors lose their contributions and the good is not provided. Everyone is better off if the good is provided than if it is not provided, but those who do not contribute are better off than those who do contribute, regardless of the outcome. Thus, individuals may be tempted to avoid contributing, free riding instead on the contributions of others. On the other hand, the presence of a threshold may act as a focal point for cooperation.

Of the many threshold public goods experiments that have been run, most have restricted participants to binary (all-or-nothing) contributions (e.g. van de Kragt et al., 1983; Rapoport and Eshed-Levy, 1989). However, the continuous contribution case, in which individuals may contribute any desired part of their endowments, better represents most attempts to raise money for threshold public goods outside the laboratory. Using the experimental method, we develop a new data base designed to facilitate the identification and examination of individual factors affecting the level of group contributions and the probability of public good provision in the threshold public goods game, concentrating on the continuous contribution case. Specifically, the effects of altering the rewards emanating from provision, allowing continuous as opposed to binary contributions, altering the threshold and introducing a money-back guarantee are each separately examined.

Isaac et al. (1989); Suleiman and Rapoport (1992); Bagnoli and McKee (1991) and Cadsby and Maynes (1998a, 1998b) have produced related experimental papers. Isaac et al. (1989) employ a framework in which a public good is provided in an amount increasing with the aggregate level of contributions as long as a specified provision-point is met. The provision-point setup differs from the threshold case in that contributions above the provision point are not wasted, but result in further group benefit. Suleiman and Rapoport (1992) consider a threshold framework in which contributions are neither binary nor continuous, but are permitted to be at any one of six integer levels. Both of these papers focus on the effects of increasing the provision point or threshold, obtaining results that appear to conflict. Through disentangling factors which covary in these earlier studies, we resolve this apparent conflict. Although Isaac et al. (1989) study the effects of a money-back guarantee in the provision-point case, neither Isaac et al. nor Suleiman and Rapoport do so in the threshold case considered here. Bagnoli and McKee (1991) examine experimentally the money-back case with continuous contributions, but do not compare it to the non-money-back case. Cadsby and Maynes (1998a) compare male and female contribution levels while Cadsby and Maynes (1998b) contrast the behavior of nurses with that of economics and business students in the threshold context. None of these papers studies explicitly the difference between the continuous and binary contribution mechanisms or examines the effect of changing average reward levels, as we do here.

This paper is organized as follows. Section 2 outlines the Nash equilibria available to participants in a threshold public goods game and specifies how these equilibria relate to the experimental treatment variables. Section 3 discusses the experimental design. The results are reported in Section 4 and conclusions are drawn in Section 5.

2. Nash equilibria of the threshold public goods game

A standard threshold public goods game with continuous contributions requires that a minimum amount of money, T, be raised from a group of individuals for provision to occur. Provision yields utility for each of the individuals involved. If more money is contributed than is necessary for provision, it is lost to the contributors, but has no effect on the level of utility associated with provision.

In the experimental framework, N individuals are provided with identical endowments, E, and must each privately decide how much of their endowment to contribute. If the threshold, T, is reached by the group as a whole, each individual receives an identical reward, R. Note that $E < T < NE$ so that it is not possible for the threshold to be reached based solely upon the contribution of one person, but it is possible for it to be attained based upon the contributions of more than one participant. Each individual chooses to contribute $c_i \in [0,E]$, where $i = 1,...,N$ and indexes individuals. Utility is induced by providing individuals with payoffs, U_i, which are a function of E, c_i and R, as indicated in expression (1):

$$\begin{aligned} &\text{If } \textstyle\sum_{i=1}^{N} c_i < T, \text{ then } U_i = E - c_i. \\ &\text{If } \textstyle\sum_{i=1}^{N} c_i \geq T, \text{ then } U_i = E + R - c_i. \end{aligned} \tag{1}$$

Of the many possible pure strategy Nash equilibria, two are symmetric in that individuals, all of whom face the same opportunities and constraints, follow identical strategies. The first symmetric pure strategy equilibrium is one in which $c_i = 0$ for all participants. This is known as the strong free-riding equilibrium. Contributing anything other than zero is suboptimal if player i believes that nobody else will make a contribution. The second symmetric pure strategy equilibrium is characterized by $c_i = T/N$ for all participants. Such an outcome just achieves the threshold and will be referred to as the symmetric threshold equilibrium. This equilibrium exists if and only if $R \geq T/N$. Contributing T/N is a best response for player i (weakly best if $R = T/N$) if he believes that each other player will also contribute T/N, so that others contribute a total of $(N-1)(T/N)$, making his T/N contribution just enough to achieve the threshold. The symmetric nature of these two equilibria may make them focal points, around which a group of non-communicating individuals might be expected to coalesce.

All of the asymmetric pure strategy equilibria are threshold equilibria in that they require that $\Sigma_{i=1}^{N} c_i = T$ and that $c_i \leq R$ for all i. With continuous contributions, there are an infinite number of contribution patterns which satisfy these constraints and hence an infinite number of asymmetric pure strategy equilibria. There are also an infinite number of mixed strategy equilibria which involve randomization between alternatives at probabilities which imply that each such alternative involves equal expected earnings.

A threshold public goods game with continuous contributions and a money-back guarantee follows identical rules, with one exception. Contributions are refunded if the threshold is not reached. Hence payoffs are specified as in Eq. (2):

$$\begin{aligned} &\text{If } \sum_{i=1}^{N} c_i < T, \text{ then } U_i = E. \\ &\text{If } \sum_{i=1}^{N} c_i \geq T, \text{ then } U_i = E + R - c_i. \end{aligned} \tag{2}$$

The symmetric pure strategy threshold equilibrium that exists in the standard case continues to exist in the money-back case. Similarly, all of the asymmetric pure strategy equilibria continue to exist, as do an infinite number of mixed strategy equilibria. The strong free-riding equilibrium also continues to exist. However, in contrast to the standard threshold case, the strong free-riding equilibrium is not strict.[1] In addition, choosing any $c_i > 0$ is also an equilibrium response as long as player i believes $\Sigma_{j \neq i} c_j + \min(E,R) \leq T$ for all i. However, once again these equilibria are not strict. Bagnoli and Lipman (1989) give further details.[2]

Threshold public goods games with binary contributions follow identical rules to the games described above, except that c_i is restricted to be either zero or E. The strong free-riding equilibrium continues to exist as do asymmetric threshold equilibria and mixed strategy equilibria satisfying the above restriction on contributions. Palfrey and Rosenthal (1984), who consider this case in detail, focus on a symmetric mixed strategy equilibrium. However, in contrast to the continuous contribution case, there is no symmetric pure strategy threshold equilibrium because T/N can be equal to neither zero nor E. The only symmetric pure strategy equilibrium is the strong free-riding equilibrium.

Nash equilibrium theory predicts that participants will choose one of these equilibria.[3] Our first treatment variable is the level of the reward. Nash equilibrium theory makes no prediction as to how the reward level might affect equilibrium selection. Our null hypothesis is that it does not. An alternative hypothesis is that a

[1] The term ''strict'' equilibrium is used by Fudenberg and Tirole (1991) to refer to an equilibrium which is ''strong'' in the sense of Harsanyi (1973). The term ''strict'' avoids confusion with alternative definitions of ''strong'' that have appeared in the literature.

[2] The money-back case is analyzed by Bagnoli and Lipman (1989) in terms of an equilibrium refinement which they develop and call undominated perfect equilibrium. This refinement eliminates all dominated strategies before applying trembling-hand perfection. They show that only the threshold equilibria satisfy this refinement in the money-back case.

[3] These Nash equilibria are for the stage game which is repeated 25 times during the course of each experiment. Subjects are informed that the game will last 25 periods in advance. Any additional equilibrium emerging from the finitely repeated nature of the game must end with a phase in which a stage-game equilibrium is being played (Benoit and Krishna, 1985). Hence the stage game equilibria discussed in the text are relevant, at least in the latter phase of each game.

higher reward will encourage selection of a threshold equilibrium, thus resulting in higher contributions and more provision. This alternative hypothesis is based upon the notion that participants may try harder to cooperate when more is at stake and is consistent with evidence from non-threshold public goods experiments (e.g. Isaac et al., 1984; Isaac and Walker, 1988).

Our second treatment variable is the type of contribution mechanism: continuous or binary. To the extent that the availability of a symmetric pure strategy equilibrium acts as a behavioral focal point, we should find more contributions and provision in the continuous contribution case which is consistent with such a threshold equilibrium, than in the binary contribution case which is not.

Our third treatment variable is the threshold level. We vary the threshold in the continuous contribution case, while holding constant net reward, the difference between average individual earnings in a threshold equilibrium and average individual earnings in the strong free-riding equilibrium.[4] When there is no money-back guarantee, increasing the threshold increases the riskiness associated with playing a strategy consistent with a threshold equilibrium since more must be contributed and hence put at risk. We predict that the extra degree of risk will cause reduced contribution levels and reduced rates of provision in the non-money-back case. However, the money-back guarantee removes the risk that a contribution made toward the public good will be lost if the threshold is not reached. Consequently, raising the threshold does not increase the risk associated with playing the strategy consistent with a threshold equilibrium and should have no impact on the achievement of the threshold equilibrium in continuous contribution games with money-back guarantees.

Our fourth treatment variable is the presence or absence of a money-back guarantee. Since the strong free-riding equilibrium is strict in the standard case but not in the money-back case, theory suggests that it is more likely to be observed in the former than in the latter instance. Hence, the money-back guarantee is predicted to discourage free riding, and encourage contributions and provision, a result which would be consistent with earlier experimental work on the binary contribution case (e.g. Dawes et al., 1986; Rapoport and Eshed-Levy, 1989).

3. Experimental design

The subjects in the experiments were randomly selected from a group of undergraduate and graduate business and economics students at York University

[4]The net reward is calculated as the gross reward minus the average contribution at the threshold equilibrium (i.e. the threshold level divided by N). Subtracting the cost of the public good from the gross reward level makes allowance for the fact that as the threshold increases, the cost of the public good also rises. For example, for $N=10$, a direct comparison of the effect of increasing the threshold in the standard case can be made between 25-token threshold experiments offering rewards of 5, 50-token threshold experiments offering rewards of 7.5 and 75-token threshold experiments offering rewards of 10. In each case, the net reward level is 2.5 tokens.

and the University of Guelph who volunteered to participate in a ''decision making game.'' All of the subjects were inexperienced in the sense that they had not participated in such an experiment before.

The basic design of the experiments is similar to the experimental designs that have been used successfully by a large number of researchers (e.g. Bagnoli and McKee, 1991; Dawes et al., 1986; Isaac et al., 1989; Orbell et al., 1988; Rapoport and Eshed-Levy, 1989; Suleiman and Rapoport, 1992; van de Kragt et al., 1983, 1986). In each experimental session, 10 randomly selected subjects are seated in a large room. At the beginning of the session, an experimenter reads aloud the instructions and the subjects follow along on their own written copies. A copy of the instructions appears in Appendix A.[5] The instructions inform the subjects that each is endowed with an initial income denominated in tokens. Their task is to individually and privately decide the number of tokens to contribute. If a stated minimum threshold number of tokens is contributed, each player receives additional tokens. In contrast to Bagnoli and McKee (1991), only one group of subjects plays the game at a time. This is to avoid any bias that might arise from several groups being able to compare their contributions after each period and thus compete against each other. At the end of the experiment, token holdings are converted into Canadian dollars at a preannounced exchange rate. The exchange rate was chosen so that the average of the payoff in the strong free-riding equilibrium with that in a threshold equilibrium would always be equal to about $28.40 Canadian. Actual average earnings varied considerably depending on the extent to which the threshold was reached in a given experiment. Each experiment lasted approximately an hour and a half.

Four variants of the threshold public goods game are conducted, corresponding to each possible scenario that results from the presence or absence of a money-back guarantee and the two possible contribution mechanisms. Each variant is conducted at three threshold and several reward levels.

The standard continuous contribution public goods game allows subjects to contribute any amount desired from their initial endowment of 10 tokens. If the threshold level is reached, each player receives an equal number of additional tokens. Each player's income equals their initial income of 10 tokens, minus their contribution, plus the additional tokens. If the threshold is not achieved, players' contributions are not returned. Each player's income equals their initial income minus their contribution.

The continuous contribution public goods game with a money-back guarantee has identical payoffs to the standard continuous contribution game if the public good is provided. However, if the contributions are not sufficient to provide the public good, all contributions are returned. In this case, each player's income is equal to their initial income.

[5]The example forms which accompanied the instructions as well as other forms used in the experiments are available from the authors upon request.

The binary contribution public goods game resembles the standard game except that it restricts players to contributing either all or none of their endowment toward the production of the public good. The binary form of the money-back guarantee game also restricts players' contributions to all or none of their endowment. If sufficient contributions are made, the public good is provided to everyone as in the standard binary game. However, if the threshold is not attained, all contributions are returned as in the money-back game.

At each session, a particular game is repeated 14 or 25 times. Repetition gives players an opportunity to learn about the game and the strategies of other players. It also permits the experimenters to see if the players converge to an equilibrium or not. Initially, following Bagnoli and McKee (1991), we ran some experiments using 14 periods. However, 14 periods did not appear to be sufficient in many cases for convergence to an equilibrium. Following Rapoport and Eshed-Levy (1989), we increased the number of periods to 25.

4. Results

In total, 45 experiments were conducted. Of these, 10 employed a 25-token threshold (YC1–YC7, YCM1–YCM2, GCM1), 28 employed a 50-token threshold (YC8–YC14, GC1–GC5, YB1–YB5, GB1–GB4, YCM3–YCM6, YBM1–YBM3) and 7 employed a 75-token threshold (YC15–YC17, YCM7–YCM8, GCM2–GCM3). The numbering of the experiments is meant to convey information about the pool from which the subjects were drawn and the variant of the game played. The subject pool is indicated by the first letter of the mnemonic: Y refers to York University economics and business students and G refers to Guelph economics and management economics students. The other letters indicate the type of experiment: C indicates continuous contributions with no money-back guarantee, B indicates binary contributions with no money-back guarantee, CM indicates continuous contributions with a money-back guarantee, and BM indicates binary contributions with a money-back guarantee.

Table 1 summarizes the results. It is divided into panels which organize experiments by type and threshold level. Within each panel, experiments are ordered by reward: the number of extra tokens awarded to each player if the threshold is achieved. The table summarizes the behavior of each group over time by indicating average group contributions by five-period intervals. In the case of 14-period experiments, the second interval includes just four periods, namely periods six to nine. The final four columns of the table report group contributions in the last period, average group contributions for the game overall, the number of times the public good is provided in the last five periods and the number of times the public good is provided throughout the entire game.

Tables 2 and 3 report regression results based on the experimental outcomes, broken down by threshold level. In Table 2, the dependent variable is the average

Table 1
Summary of results of experiments

Session	Reward	Average group contribution							Times public good provided	
		Periods 1-5	Periods 6-10	Periods 11-15	Periods 16-20	Periods 21-25	Last Period	Overall	Periods 21-25	Overall
Panel A: Results of continuous contribution public goods games with 25 token threshold										
YC1	5	19.0	14.8[a]	6.8[b]	–	–	0.0	14.0	0	1[c]
YC2	5	26.2	15.9	7.5	1.5	3.3	2.5	10.9	0	2
YC3	11	21.0	22.9	15.4	12.0	1.3	0.0	14.5	0	3
YC4	17.5	26.7	23.8	28.2	23.7	33.8	26.5	27.2	5	16
YC5	20	23.7	26.9[a]	27.7[b]	–	–	36.0	26.0	4	9[c]
YC6	20	25.3	25.6	25.8	23.8	24.9	26.5	25.1	2	16
YC7	27.5	25.2	22.5	25.4	25.7	25.7	26.0	24.9	3	13
Panel B: Results of continuous contribution public goods games with 50 token threshold										
YC8	7.5	39.0	11.4	7.0	0.2	0.3	1.1	11.6	0	0
GC1	7.5	15.8	11.4	26.0	0.4	0.0	0.0	10.72	0	0
YC9	11	41.3	43.4	29.6	10.5	33.0	40.5	31.6	0	2
YC10	11	24.4	37.2	21.0	10.4	10.4	20.0	20.7	0	1
GC2	11	46.9	43.9	46.0	44.3	31.9	12.0	42.6	0	6
YC11	20	44.6	41.6[a]	34.5[b]	–	–	20.0	40.6	0	3[c]
YC12	20	43.6	45.9	45.9	51.6	48.0	47.0	47.0	1	9
GC3	20	41.3	46.2	34.4	12.0	7.0	5.0	28.2	0	1
YC13	30	39.4	47.5	32.7	12.8	5.7	0.0	27.6	0	1
GC4	30	53.3	48.1	42.7	42.7	50.9	49.5	49.2	3	11
YC14	40	42.2	50.2	48.8	49.7	49.2	51.5	48.0	2	9
GC5	40	51.1	50.2	51.2	49.7	50.8	54.0	50.6	4	15
Panel C: Results of continuous contribution public goods games with 75 token threshold										
YC15	10	35.6	13.0	19.6	4.5	2.2	0.7	15.0	0	2
YC16	22.5	65.5	32.6	39.0	57.1	31.1	9.5	45.1	0	0
YC17	32.5	51.7	76.3	50.5	16.2	3.6	10.0	39.7	0	4
Panel D: Results of continuous contribution games with money back guarantee and 25 token threshold										
GCM1	5	24.5	22.8	22.3	23.2	22.2	19.8	23.0	0	4
YCM1	20	23.6	25.8[a]	24.5[b]	–	–	20.0	24.6	4	10[c]
YCM2	20	26.2	24.1	21.2	25.4	26.3	26.5	24.6	3	12

Panel E: Results of continuous contribution games with money back guarantee and 50 token threshold									
YCM3	7.5	45.5	47.2	48.4	46.9	49.2	49.0	47.4	2	7
YCM4	11	44.8	45.4	40.8	46.2	48.2	47.0	45.2	1	5
YCM5	20	44.2	46.1	49.0	49.7	53.4	56.0	48.5	4	11
YCM6	30	48.8	49.5	51.3	52.2	50.3	58.5	50.4	3	15
Panel F: Results of continuous contribution games with money back guarantee and 75 token threshold										
YCM7	10	67.1	72.5	72.0	74.4	73.8	74.7	72.0	0	2
YCM8	10	67.1	66.0	66.2	69.9	65.9	68.5	67.0	0	3
GMC2	22.5	71.9	66.2	74.3	72.9	72.2	72.1	71.5	2	10
GMC3	32.5	71.4	73.1	68.1	75.0	75.7	73.4	75.6	4	9
Panel G: Results of binary contribution public goods games with 50 token threshold										
YB1	11	12.0	6.0	16.0	34.0	14.0	10.0	16.4	0	1
GB1	11	14.0	20.0	18.0	2.0	0.0	0.0	10.8	0	0
YB2	20	42.0	22.5[a]	36.0[b]	–	–	10.0	33.3	1	3[c]
GB2	20	38.0	20.0	6.0	6.0	6.0	0.0	15.2	0	2
YB3	30	34.0	12.0	16.0	4.0	4.0	10.0	14.0	0	1
GB3	30	36.0	24.0	18.0	12.0	24.0	20.0	22.8	0	2
YB4	40	34.0	44.0	40.0	42.0	46.0	40.0	41.2	2	9
GB4	40	32.0	24.0	28.0	28.0	42.0	20.0	30.8	3	7
YB5	85	70.0	56.0	58.0	64.0	58.0	70.0	61.2	4	23
Panel H: Results of binary contribution games with money back guarantee and 50 token threshold										
YBM1	11	36.0	30.0	32.0	36.0	30.0	10.0	32.8	1	4
YBM2	20	36.0	46.0	40.0	36.0	42.0	30.0	40.0	2	8
YBM3	30	44.0	46.0	48.0	44.0	42.0	50.0	44.8	2	10

[a]For 14-period experiments, the second interval covers only 4 periods, from 6 to 9.
[b]For 14-period experiments, the third interval covers from period 10 to 14.
[c]The number of times the public good is provided is not strictly comparable in the 14-period experiments to the number for the 25-period experiments.

Table 2
Results from regression of average level of contributions in the last five periods on experiment characteristics[a]

Regressor	25-token threshold	50-token threshold	75-token threshold
Intercept	2.61	-0.08	7.78
	(0.49)	(-.01)	(0.63)
Reward	0.99	0.78	0.21
	(2.79)*	(4.41)**	(0.44)
Continuous contribution dummy	–	11.26	–
		(2.01)*	
Money back guarantee dummy	6.89	24.30	60.20
	(1.17)	(3.90)**	(6.59)**
Adjusted R^2	0.44	0.50	0.87
Number of observations	10	28	7

[a], *T*-statistics are in parentheses.
*, Significant at the 5% level, using one-tailed test.
**, Significant at the 1% level, using one-tailed test.

Table 3
Results from regression of number of times public good is provided in the last five periods on experiment characteristics[a]

Regressor	25-token threshold	50-token threshold	75-token threshold
Intercept	-0.96	-1.17	-2.22
	(-0.97)	(-2.71)**	(-1.97)
Reward	0.20	0.07	0.10
	(3.50)**	(6.26)**	(2.36)*
Continuous contribution dummy	–	0.64	–
		(1.83)*	
Money back guarantee dummy	0.36	1.67	1.80
	(0.39)	(4.32)**	(2.17)*
Adjusted R^2	0.54	0.67	0.54
Number of observations	10	28	7

[a], *T*-statistics are in parentheses.
*, Significant at the 5% level, using one-tailed test.
**, Significant at the 1% level, using one-tailed test.

level of contributions during the last five periods.[6] In Table 3, the dependent variable is the number of times the public good is provided during the last five periods. In both tables, the independent variables include the reward level and a dummy variable equal to one for the money-back guarantee experiments and zero otherwise. Since the 50-token threshold regression includes data from both binary and continuous contribution experiments, it also employs a dummy variable set equal to one for the continuous contribution experiments and zero otherwise.

For reward, the null hypothesis predicted by Nash equilibrium theory is that increases will have no effect on either dependent variable. For both the 25-token and 50-token threshold cases, this hypothesis is rejected in favor of the alternative that a higher reward level will be associated with both more contributions and more provision. Even the small number of 75-token threshold experiments reject the null with respect to provision, although not with respect to contributions. The effect of reward is highlighted by Figs. 1 and 2 which show group contributions by period for two standard, 50-token threshold, continuous contribution experiments: low-reward YC8 and high-reward GC4. YC8 with a reward of 7.5, converges to the strong free-riding equilibrium with negligible contributions and no provision in the last five periods. In contrast, GC4 with a reward of 30, moves close to a threshold equilibrium, exhibiting substantial contributions and providing the public good three times in the last five rounds.

Although on average higher rewards are associated with more contributions and provision, considerable variation exists. For example, in one session of the continuous contribution game with a 30-token reward, the public good was

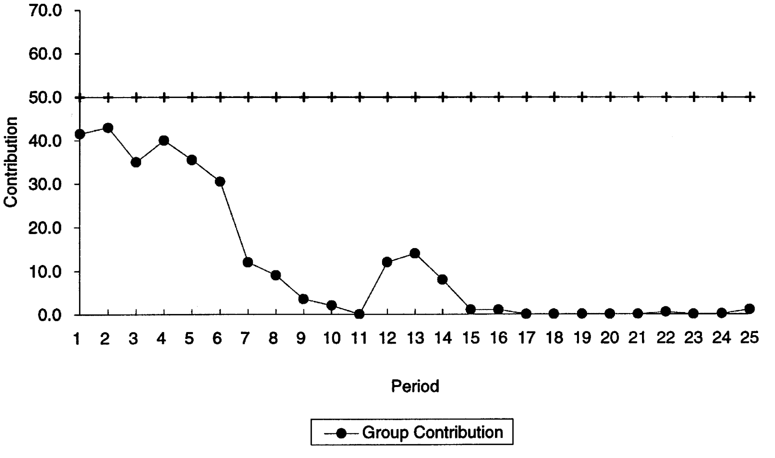

Fig. 1. Contribution by period: Session YC8. Reward = 7.5 per player. Threshold = 50 tokens.

[6] We also ran regressions using the group contribution in the last period as the dependent variable. The results were similar to those reported in Tables 2 and 4.

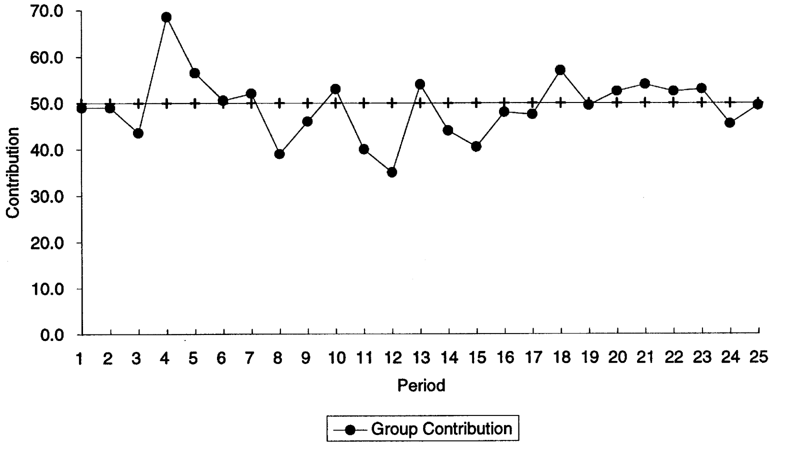

Fig. 2. Contribution by period: Session GC4. Reward = 30 per player. Threshold = 50 tokens.

provided only once (YC13) and in another, it was provided 11 times (GC4). An examination of the individual contributions shows that two of the 10 players in the first session consistently free rode. One never contributed and the other contributed an average of just 0.36 tokens per period.

For the contributions mechanism, the null hypothesis of no difference between binary and continuous contributions is tested against the alternative that allowing continuous contributions encourages both contributions and provision. The null hypothesis is rejected in favor of the alternative both for average contribution level in the last five rounds and for the number of times the public good was provided in those rounds. Fig. 3 illustrates YB3, a binary contribution experiment with a reward of 30, which when compared with GC4 in Fig. 2, demonstrates the tendency toward lower contributions, *ceteris paribus*, in the binary case. However, once again there is considerable variation between experiments.

To study the effect of varying the threshold, we run regressions combining the data from the continuous contribution experiments at all three threshold levels. In Table 4, the dependent variable is the average contribution in the last five periods as a fraction of the threshold level. In Table 5, the dependent variable is the number of times the public good is provided in the last five periods. The first two columns in each table report results separately for the 22 standard continuous contribution experiments with no money-back guarantee and the 11 continuous contribution experiments with a money-back guarantee. The independent variables are the net reward level and the threshold level.

The regression results clearly demonstrate the significantly negative impact of raising the threshold in the standard case. For those experiments in which no money-back guarantee is given, the coefficient on threshold level is significantly negative for both dependent variables. The presence of a money-back guarantee

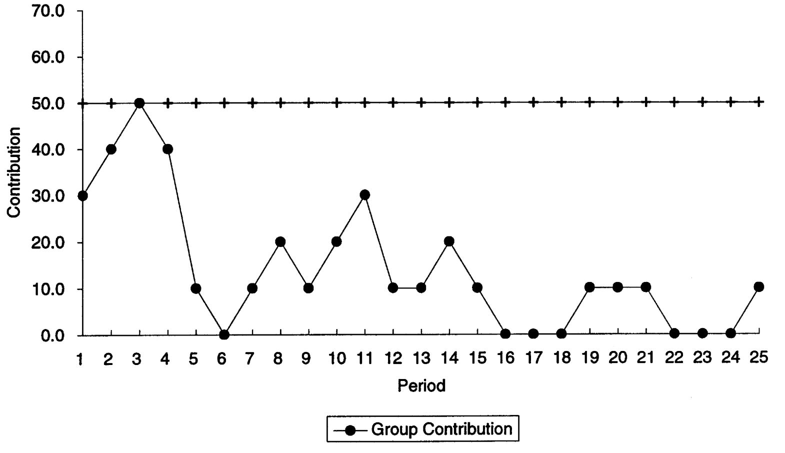

Fig. 3. Contribution by period: Session YB3. Reward = 30 per player. Threshold = 50 tokens.

Table 4
Results from regression of average level of group contribution in the last five periods as a fraction of threshold level on experiment characteristics, combining results of continuous contribution experiments at all threshold levels[a]

Regressor	With no money back guarantee	Only money back guarantee	Full sample I	Full sample II
Intercept	0.68 (2.84)**	0.95 (18.86)**	0.55 (3.09)**	0.68 (3.37)**
Net reward (NR)	0.03 (3.40)**	0.004 (2.07)*	0.02 (3.29)**	0.03 (4.04)**
Threshold level (T)	-0.01 (-2.41)*	-0.000 (-0.35)	-0.01 (-1.95)*	-0.01 (-2.86)**
Money back guarantee dummy (MBG)	–	–	0.53 (4.44)**	0.27 (0.77)
MBG·NR	–	–	–	-0.02 (-1.76)*
MBG·T	–	–	–	0.01 (1.82)*
Adjusted R^2	0.40	0.20	0.44	0.52
Number of observations	22	11	33	33

[a], T-statistics are in parentheses.
*, Significant at the 5% level, using one-tailed test.
**, Significant at the 1% level, using one-tailed test.

Table 5
Results from regression of number of times public good is provided in the last five periods on experiment characteristics, combining results of continuous contribution experiments at all threshold levels[a]

Regressor	With no money back guarantee	Only money back guarantee	Full sample I	Full sample II
Intercept	1.80 (2.23)*	1.02 (1.13)	1.03 (1.62)	1.80 (2.37)*
Net reward (NR)	0.10 (3.91)**	0.15 (4.61)**	0.11 (5.33)**	0.10 (4.15)**
Threshold level (*T*)	-0.05 (-3.00)**	-0.01 (-0.99)	-0.03 (-2.95)**	-0.05 (-3.18)**
Money back guarantee dummy (MBG)	–	–	1.51 (3.50)**	-0.78 (-0.59)
MBG·NR	–	–	–	0.05 (1.19)
MBG·*T*	–	–	–	0.03 (1.45)
Adjusted R^2	0.49	0.68	0.55	0.57
Number of observations	22	11	33	33

[a], *T*-statistics are in parentheses.
*, Significant at the 5% level, using one-tailed test.
**, Significant at the 1% level, using one-tailed test.

dramatically alters the impact of raising the threshold. In that case, the coefficient on the threshold level is not significantly different from zero for either dependent variable.

For the money-back guarantee, the null hypothesis that its presence makes no difference to the experimental outcome is rejected in favor of the alternative that it is associated with higher contributions and more provision in both the 50-token and 75-token threshold cases (Tables 2 and 3). Fig. 4 illustrates YCM3, a 50-token threshold money-back experiment with a low reward of 7.5. Comparing it with the results of YC8 in Fig. 1, dramatizes the difference made by such a guarantee. In contrast, the money-back dummy is not significant in the 25-token threshold case, regardless of the dependent variable.

The fact that threshold matters in the standard case but not in the money-back case, as well as the fact that the money-back guarantee leads to significantly more contributions when the threshold is high but not when it is low, suggest interaction effects between threshold level and the presence or absence of a money-back guarantee. The last two columns of Tables 4 and 5 report two regressions using the

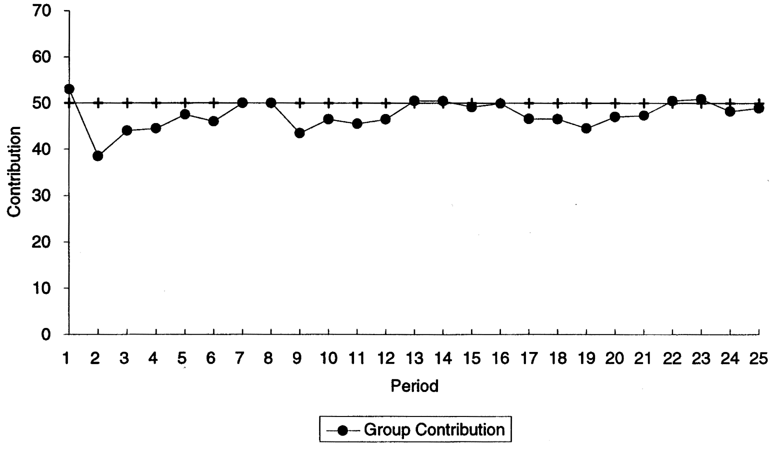

Fig. 4. Contribution by period: Session YCM3. Reward = 7.5 per player. Threshold = 50 tokens.

entire sample of continuous contribution experiments in order to examine this possibility, as well as the possibility of similar interaction between net reward and the money-back guarantee. The first full-sample regression ignores the possibility of interaction effects, simply inserting a dummy variable equal to one for the money-back guarantee experiments and zero otherwise. For both dependent variables, this dummy variable is significant. The second full-sample regression adds interaction dummies for threshold level and net reward. The addition of the interaction dummies causes the money-back intercept dummy to lose its significance in the case of both dependent variables. In contrast, the interaction dummy for threshold is significant for the contributions data (Table 4) and marginally significant (at just the 10% level) for the number of times the public good is provided in the last five periods (Table 5). Finally, the interaction dummy for net reward is significant for average contributions as a fraction of threshold in the last five periods (Table 4). However, it is not significant for the number of times the public good is provided in the last five periods (Table 5).

The money-back guarantee encourages contributions and provision, but in a manner which interacts with both the threshold and the net reward levels. Specifically, it has a greater impact on both the contribution–threshold ratio and the extent of provision when threshold levels are relatively high. For a sufficiently high reward level, a low threshold is likely to elicit enough contributions to achieve provision, even in the absence of a money-back guarantee. Adding such a guarantee makes little difference since there is no point in contributing more than the threshold. However, a high threshold encourages free-riding in the standard case because of the increased risk of contributing, *ceteris paribus*. A money-back guarantee generally has a strong impact in such a case, encouraging contributions and provision by eliminating the risk of losing one's contribution when the threshold is not met. These results are of course just the flip side of the previously reported observation that raising the threshold discourages contributions and provision in the standard case, but not in the money-back case.

The money-back guarantee has a weaker impact on the contribution–threshold ratio when the reward level is high than when it is low. A high reward elicits sufficient contributions to attain the threshold often, even in the standard case. A money-back guarantee makes little or no difference in such an instance. In contrast, when the reward is low, a money-back guarantee keeps contributions considerably higher than they would have been in the absence of such a guarantee, though often not quite high enough to obtain provision, as illustrated by YCM3 in Fig. 4. Apparently, the money-back guarantee does not stop players from trying to get away with contributing less. However, in contrast to the standard case, where such behaviour tends to cause others to reduce their contributions to zero in fear of needlessly losing money, the guarantee eliminates this fear, providing others with an incentive to keep trying.

Since low reward money-back experiments often hover just below the threshold, an increase in the reward level tends to have a relatively small effect on contributions, but one which translates into a large effect on provision. Indeed, the significantly negative reward–money-back interaction dummy for the contribution-based dependent variable tells us that reward has significantly less impact on contributions in the money-back than in the standard case. However, the insignificant coefficient on the comparable dummy in the provision-based regression confirms that where provision is concerned, net reward is equally important in the money-back and standard cases.

An interesting aspect of these experimental results which we had not anticipated is the large number of times a one-shot equilibrium is reached, but then abandoned. A similar observation was made in an entirely different context by Cadsby et al. (1998). Not only do players abandon the strong free-riding equilibrium to try to encourage the group to move to the threshold, they also often abandon a threshold equilibrium, especially if it is not symmetric. Presumably this is an attempt to get others to contribute more towards the public good.

5. Discussion and conclusion

In many previous studies, the experimental evidence indicates that free-riding tends to increase in repeated rounds of public goods games. Dawes and Thaler (1988) provide a review of this literature and Rapoport and Eshed-Levy (1989) present evidence of this phenomenon in the binary contribution threshold setting. In contrast, our experiments provide many examples where groups move toward cooperation rather than free-riding over time. Indeed, our results indicate that a deterioration in the level of contributions is a special case, occurring only when the incentives to reach an efficient equilibrium are relatively low. The more general result is that contributions move toward a Nash equilibrium over repeated rounds of a public goods game.

Of course, the threshold setting itself provides an incentive to contribute since, in contrast to the non-threshold case, it is consistent with many cooperative and efficient Nash equilibria. However, the setting itself is not sufficient to overcome strong free riding. By developing an experimental data base which allows us to identify the individual effects of allowing continuous contributions, altering the threshold level, providing a money-back guarantee, and increasing reward, we have been able to examine the role played by each of these variables in helping to create the necessary incentives for the voluntary contribution mechanism to produce a cooperative and efficient outcome.

All four treatment variables turn out to be important determinants of group behavior. Allowing continuous contributions facilitates both contributions and provision, because it gives the group a cooperative outcome which is symmetric in pure strategies on which to focus. The symmetric threshold strategy involves contributing 2.5 tokens in 25-token threshold games, 5 tokens in 50-token threshold games and 7.5 tokens in 75-token threshold games. None of our groups of subjects ever exactly played the symmetric threshold equilibrium. However, in those experiments which were closer to a threshold equilibrium than to the strong-free-riding equilibrium in each of the last five rounds, 45.3% of the subjects played the symmetric threshold strategy in the first round, and 23.7% played it in the last five rounds. Many other subjects made contributions very close to that dictated by the symmetric strategy. For example, in the first round, 68.4% of participants made contributions between the two integers surrounding the symmetric number.[7] In the last five rounds, the comparable number was 44.7% No such strategy is available in the binary case. Although its availability did not attract everyone, it attracted enough subjects initially to bring groups reasonably close to the threshold. By the last five rounds, many subjects had adjusted their contributions up or down in reaction to the decisions of others in their group, and yet substantial numbers continued to contribute close to the symmetric amount.

Raising the threshold in the continuous contributions game, while holding net reward constant, makes achievement of the equilibrium more difficult in the standard, but not in the money-back case. Suleiman and Rapoport (1992) also report results from a standard threshold public goods experiment which show a decline in provision as the threshold increases. However, Suleiman and Rapoport use the same gross reward in all of their experiments. This implies a net reward which falls as the threshold rises. We have shown that both the contribution–threshold ratio and the number of times the public good is provided fall not only as the threshold rises, but also as the net reward falls. The perfect negative correlation

[7] The ranges are 2–3, 4–6 and 7–8 respectively. We chose to report these particular ranges because most subjects not choosing the symmetric strategy chose to contribute an integer amount.

between threshold and net reward in Suleiman and Rapoport prevents the two effects from being identified separately, as in our experiments.

Suleiman and Rapoport, in discussing the relationship between contributions and threshold, suggest that for the parameters used in their study, efficiency is at its maximum when $T/N=E/2$. In our study, this condition is satisfied when $T=50$. They hypothesize that lower thresholds result in overprovision, while higher thresholds result in underprovision. While carefully indicating that this suggestion holds only for the parameters used in their study, they suggest that further studies be undertaken to test their hypothesis under alternative conditions. By allowing net reward to vary independently of threshold and showing that it also affects the contribution–threshold ratio and hence efficiency, we have confirmed that the notion of an optimum threshold is meaningless, unless other parameters such as net reward are given.[8]

Isaac et al. (1989) report results of experiments in which a public good is continuously provided once contributions have reached a particular level, analogous to our threshold, which they call the provision point. They employ three different provision points, referred to as low (LPP), medium (MPP) and high (HPP). They report that with no money-back guarantee, the provision point level does not appear to affect the outcome in the latter periods of the game. However, when a money-back guarantee is added, provision of the public good is dramatically improved in the MPP and especially the HPP environments. This suggests that the provision point level is unrelated to the level of contributions or the extent of provision in the absence of a money-back guarantee, but positively related to contributions and provision in its presence, appearing to contradict both Suleiman and Rapoport (1992) and our results.

The key to understanding Isaac et al.'s (Isaac et al., 1989) results is to realize that in their setup, as in Suleiman and Rapoport (1992), net reward is perfectly correlated with provision-point or threshold level. However, in contrast to Suleiman and Rapoport, the correlation is not negative, but positive.[9] Thus, reward rises in lockstep with provision-point level. In the absence of a money-back guarantee, the positive effect of the increasing net reward on contributions and provision appears to offset the negative effect of the increasing provision point. Therefore, increasing the provision-point level seems to have no effect at all on behaviour. When a money-back guarantee is added, we have shown that increasing the threshold level has no significant effect on contributions or provision.

[8]It would appear that even Suleiman and Rapoport's own results fail to satisfy their suggestion. For example, consider a threshold level of 15. In this case, $T/N=3> E/2=2.5$. Hence their hypothesis predicts underprovision. However, Suleiman and Rapoport report that it is 10% overprovision that actually occurs.

[9]In Isaac et al. (1989), the gross reward is defined as $0.3\cdot$(group contribution), at or above the provision point. If the provision point is just achieved, net reward is $0.3\cdot(T)-T/4$, where T is the provision point or threshold. Thus, net reward is 5.4 at the provision point 108, 10.8 at the provision point 216 and 12.4 at the provision point 248.

However, increasing reward does have a small significant effect on contributions and a larger significant effect on provision. Reward increases with provision-point level in Isaac et al. (1989), drawing contributions up slightly and provision up a lot. By permitting threshold and net reward to vary independently in our experiments, we are able to disentangle the distinct effects of these two independent variables and resolve the apparent contradiction concerning the effects of varying threshold level between the Suleiman and Rapoport (1992) and the Isaac et al. (1989) results.

A money-back guarantee also encourages contributions and provision, not only in the binary case documented previously, but in the continuous case as well. However, the effects of a money-back guarantee are much greater when the reward level is low and/or the threshold level is high. A money-back guarantee will have little or no effect if the threshold would have been achieved without it.

Finally, the level of the reward is critical to consistent provision. It is not sufficient for provision to be socially efficient. When the gains from achieving efficiency are small, contributions collapse to zero in the standard case and hover just below the threshold in the money-back case, achieving the threshold only occasionally. Increasing those gains by raising the reward level encourages contributions and provision. The rewards emanating from provision must be substantial in order to attract groups toward an efficient threshold equilibrium, even with continuous contributions, a low threshold and a money-back guarantee.

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Appendix A

Experimental instructions

This is an experiment in the economics of decision making. Several research organizations have provided funds for this research. The instructions are simple and, if you follow them carefully and make good decisions, you may earn a considerable amount of money. This money will be paid to you by cheque at the end of the experiment.

You have been organized into a group. Each group will consist of the same persons for the duration of the session. The session will last for twenty five periods. In each period you will be required to make a decision and your total income will depend on these decisions. You may not communicate with anyone else in the room during the session.

The actual number of persons in your group, along with other information, is reported on a set of *information slips* that have been provided to you. You have been given one slip for each period of the session. On each slip you should enter the date, the scheduled starting time, your assigned player number and the period.

At the beginning of each period, you will receive an income in tokens as stated on your *information slips*. These tokens will be exchanged for money at a rate stated on these slips. Also provided is the income of each of the other persons in your group. This is private information; you are not to reveal it to anyone else in the room.

You will be asked to post a contribution in each period. You will have three minutes to enter your contribution. You may enter any contribution from zero up to the amount of your income for the entire period. Contributions in excess of your income will not be accepted. Enter your contribution in the space on the *information slip* provided as well as on the *profit calculation slip*. You may contribute part tokens, e.g. 4.5 tokens.

Once your contribution has been entered, please raise your hand and your *information slip* will be collected by the persons running the session. If the sum of the contributions of the persons in your group meets or exceeds the threshold level that is stated on your *information slips*, you will each receive an additional bundle of tokens. The size of this addition for the group, and for yourself, is also stated on the *information slips*. Your total income for the period will be your initial income, plus the additional tokens, minus your contribution.

If the sum of the contributions is less than the threshold level the additional tokens will not be provided. In this event, your total income for the period will simply be your original income, minus your contribution.

At the end of each period, the persons running the session will inform you whether your group has obtained the additional tokens. The total contributions of your group, but not the contributions of the individual members, will be posted on the board. You should then fill out the rest of your *profit calculation slip* to determine your earnings for the period in dollars. Once you have calculated your profits, you will be ready to begin the next period. Please note that your initial income in each period is independent of (i.e. is unaffected by) your profits in the previous period. The initial income is always as specified on the information slip for the current period.

At the end of the session, you will be called up one at a time and paid by cheque the total amount that you earned for all periods in the session. All slips used in the session should be returned at that time.

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