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**Effects of Group Size and Contribution Mechanism
On Cooperation in Threshold Public Goods and Commons
Experiments**

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計畫主持人：徐麗振

研究助理：紀志雲

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Effects of Group Size and Contribution Mechanism on Cooperation in Threshold Public Goods and Commons Experiments

Li-Chen Hsu^{*}

Abstract: We examine cooperation in threshold public goods and commons games by considering different group sizes and contribution mechanisms. Our experimental evidence shows first that cooperation is significantly different between public goods and commons experiments when group size is small and when contributions are continuous. Second, continuous contributions greatly raise cooperation in both public goods and commons experiments when group size is large. Third, continuous contributions greatly alleviate the incentive of complete free-riding in both public goods and commons experiments, regardless of the group size. Finally, threshold Nash equilibria are reached more often in all experiments than the complete free-riding Nash equilibrium.

摘要：本文探討有門檻的公共財與共同資源賽局中群體規模與捐贈機制對合作行為的影響。我們的實驗數據顯示：(1) 在小群體以及連續捐贈的機制下，公共財與共同資源賽局中的合作行為有很明顯的差異。(2) 在大群體中，連續捐贈的機制明顯提高公共財與共同資源實驗中的合作率。(3) 不論在小群體或大群體，連續捐贈的機制大幅減輕公共財與共同資源實驗中完全免費乘車的動機。(4) 在所有的實驗中，有門檻的 Nash 均衡達成的頻率較完全免費乘車的 Nash 均衡高。

Keywords: Framing; Group Size; Binary Contributions; Continuous Contributions; Threshold

JEL Classification: C91; D72

^{*} Graduate Institute of Public Finance, National Chengchi University, 64, Sec. 2, Chih-Nan Rd., Taipei 11623, Taiwan; Tel: 886-2-2938-7313; Fax: 886-2-2939-0074; e-mail: lchsu@nccu.edu.tw. Financial support from the National Science Council is greatly acknowledged.

1. INTRODUCTION

Decision framing, which is initiated from the Prospect Theory developed by Kahneman and Tversky (1979, 1982, 1984), has been discussed broadly on some economic issues, for instance, the public goods/commons dilemma, preference reversals, and the disparity between willingness to pay and willingness to accept.¹ These issues are of particular interest because economic theories usually predict the same conclusion regardless of the way that the problem is framed, while experimental evidence often finds differences, despite that the potential outcomes in both frames are identical. Among these issues, the public goods/commons dilemma has been examined in various frameworks by both economists and psychologists. Unfortunately, results are generally inconsistent and thus this issue has not yet been resolved.

Most experimental studies examining this issue instruct subjects to “give some” in the public goods experiments and instruct subjects to “take some” in the commons.² Among these studies, some find higher cooperation in public goods experiments than in commons experiments, some find the opposite, and some find no difference between these two frames. Specifically, Sonnemans, Schram, and Offerman (1998) examine the public goods/commons dilemma in a step-level public goods/commons mechanism, in which the public good is provided if a threshold is reached, and the common resource is gone if a threshold is broken. In their experiments subjects are randomly assigned to groups of five and play the game for twenty rounds. Subjects’ decisions are binary that they can only choose to give to (take from) the public good (common resource) or not. The main finding in their experiments is that subjects are significantly more cooperative in public goods experiments than in common resources experiments. Aquino, Steisel, and Kay (1992) also test the public goods/commons dilemma in a binary contribution step-level mechanism, but instead use group size of four and instruct subjects to play only one round. In contrast to Sonneman, Schram, and Offerman, they find no framing effect.

Instead of binary decisions, Rutte, Wilke, and Messick (1987) and Van Dijk and Wilke (1995) also examine the public goods/commons dilemma in a step-level mechanism but allow continuous contributions. In Rutte, Wilke, and Messick (1987), subjects are assigned to groups

¹ See surveys by Davis and Holt (1993) and Kagel and Roth (1995) for details.

² An exception is Andreoni (1995), who examines the puzzle between public goods and commons by using an externality framework.

of five or six and play only one shot. No framing effect is found and thus Rutte, Wilke, and Messick conclude that framing effect may only hold under conditions in which subjects face a sequence of decisions. Van Dijk and Wilke (1995) conduct one-shot experiments by using group size of four, but in a slightly different environment in which group members are assigned asymmetric endowments and asymmetric interests. They find that subjects playing a public good game tend to give in proportion to their endowments or interest position, and subjects playing a common game coordinate their behavior to minimize the difference in final outcomes.

Different from all the studies above, in Brewer and Kramer (1986) and Fleishman (1988) subjects' decisions are continuous and no threshold is imposed. Brewer and Kramer manipulate the experiments in two group sizes, eight and thirty-two, and assume that the public good and common resource increase by a replenishment factor that is between 1% and 10%. They find that subjects are less cooperative in the public good experiments than in the common resource experiments. In addition, in the public good experiments subjects are less cooperative in larger groups, while in the common resource experiments no group size effect is found. In Fleishman (1988), subjects make a series of nine decisions, but they are not told the exact number of round in the series. Instead, he finds no framing effect.

Observing from the experimental studies above, some test the public goods/commons dilemma for only one shot, some test this dilemma repeatedly in ten or twenty independent rounds, and some test this dilemma in a dynamic framework in which the public good or the common resource can be replenished. In addition to the diversity in the repetition of rounds, whether a threshold is imposed and whether subjects are instructed to give/take in a binary or continuous manner also differ among previous studies. Furthermore, group sizes are different too. Except Brewer and Kramer (1986) who also examine the group size effect, all others allow only small sizes of groups. Due to all these disparities, experimental results from various studies can hardly be compared.

This paper will concentrate on examining the cooperation in threshold public goods and commons games. Because in a small group any group member can easily be pivotal when contributions to a threshold public good or common pool are binary, and we conjecture that being pivotal may affect subjects' incentives to cooperate in different frames, we explore the public goods/commons dilemma by considering different group sizes and contribution mechanisms. Public goods and common resources games are each examined in groups of five and groups of

twenty, and each group size is accompanied by binary and continuous contribution mechanisms. The main result of this study is that subjects in groups of five are more cooperative in the public goods experiment than in the common resources experiment, regardless of the contribution mechanism. However, in groups of twenty the opposite result that cooperation is higher in the common resources experiment than in the public goods experiment is found when contributions are continuous, and no difference can be found when contributions are binary.

Section 2 will present the models for threshold public goods and common resources games and will briefly characterize the Nash equilibria. Section 3 describes the experimental design and Section 4 presents experimental results. Section 5 concludes.

2. NASH EQUILIBRIA IN THRESHOLD PUBLIC GOODS AND COMMON RESOURCES GAMES

This section introduces models of threshold public goods and common resources games and presents the Nash equilibria. It is assumed in the model that no refund will be applied if contributions fail to meet the threshold, and any contributions above the threshold will be wasted. The model of the threshold public goods game was introduced by van de Kragt, Orbell, and Dawes (1983), Bagnoli and Lipman (1989), and developed and tested in laboratories by Marks and Croson (1998) and Cadsby and Maynes (1999). In addition, Andreoni (1998) presents a fund-raising model in which some cases are similar to the above threshold models. Individuals are each endowed with wealth w and allocates the wealth between consumption of the private good, x_i , and donation to the public good, g_i . Note that g_i is equal to either 0 or w with binary contributions. In the threshold public goods game the public good, G , will be provided if and only if the group contribution exceeds a certain threshold, T . It is assumed in the model and the experimental design that the portion of group contribution exceeding T will be wasted and that no refund will be made if group contribution falls below T . It is assumed further that T is a multiple of w to prevent unnecessary waste. Let $\sum_{i=1}^n g_i$ be the total gifts contributed by all group members, the level of the public good is therefore

$$G = \begin{cases} T & \text{if } \sum_{i=1}^n g_i \geq T \\ 0 & \text{if } \sum_{i=1}^n g_i < T. \end{cases}$$

Each individual decides between contributing and not contributing to maximize his or her utilities. Individuals' preferences are represented by the utility function $u_i(x_i, G) = x_i + B$, where B represents the benefits from consuming the public good. It is assumed in the experimental design that $B = a(G/nw)$, that is, if the group contribution reaches or exceeds a certain fraction of the group endowment, each group member will obtain a bonus which is a multiple of a of this fraction. Otherwise, $B = 0$ and the utility comes solely from the private consumption. For instance, let $n = 5$, $w = 100$ points, and $a = 500$. If three or more than three group members contribute to the public good, or equivalently, 300 or more than 300 points of the group endowment are allocated to the public good, the public good will be provided and each group member will get a bonus of 300 points. Otherwise, $G = 0$ and as a consequence $B = 0$. Note that the condition $w < T < nw$ is required so that individuals have incentives to contribute and to free ride.

In this framework any individual i will contribute if and only if he or she is pivotal, that is, $g_i = w$ if and only if $T - \sum_{j \neq i} g_j = w$. Nash equilibria in this threshold public goods game, as solved by Cadsby and Maynes (1999), are the following. First, we have a complete free-riding Nash equilibrium in which no one contributes and therefore $G = 0$, since the best response for $\sum_{j \neq i} g_j = 0$ is $g_i = 0$ for all i . Second, we have asymmetric pure strategy Nash equilibria in which $\sum_j g_j = T$. When group contributions exactly match the threshold, if individual i is not a contributor, the best strategy for him is to keep not contributing. In contrast, if individual i is a contributor, the best strategy for him is to remain a contributor. Third and the final, we have an infinite number of mixed strategy Nash equilibria in which individuals randomize the probabilities of contributing and not contributing such that the sum of the expected contributions of all group members is exactly equal to T . Following Cadsby and Maynes (1999), we call the Nash equilibria in which the group contributions precisely match the threshold the threshold Nash equilibria. Obviously threshold Nash equilibria are also Pareto efficient.

The above threshold public goods game can be easily transformed into a threshold common

resources game. Let G now denote the common resource, \bar{G} the initial size of the common resource, and n still represent the group size. Individuals each are endowed with nothing, but an entitlement to exploit the common resource, w , such that $nw = \bar{G}$. The amount individual i exploits from the common resource will be his or her consumption of the private good, x_i , which is equal to 0 or w when exploitations are binary. The amount individual i leaves in the common resource is thus $g_i = w - x_i$ and the total leftover is $\sum_i g_i = \bar{G} - \sum_i x_i$. If total exploitation, $\sum_i x_i$, exceeds a threshold, \bar{T} , or equivalently, if the total leftover, $\sum_i g_i$, drops below $T = \bar{G} - \bar{T}$, the common resource is gone; otherwise, the common resource remains and is equal to T . That is

$$G = \begin{cases} \bar{G} - \bar{T} & \text{if } \sum_{i=1}^n x_i \leq \bar{T} \\ 0 & \text{if } \sum_{i=1}^n x_i > \bar{T}. \end{cases}$$

Individuals behave to maximize the same utility function $u_i(x_i, G) = x_i + B$ as in the case of public goods game, but by choosing x_i instead of g_i . Note that the condition $\bar{G} - w > \bar{T} > 0$, which is identical to the condition $w < T < nw$ in the public goods game, must be imposed so that individuals have incentives not to exploit the common resource and to free ride.

We can see that the threshold common resources game is identical to the threshold public goods game. In the threshold common resources game with binary contributions (or more precisely, exploitations), the individual will exploit the common resource if and only if he is not pivotal, that is, $x_i = w$ if and only if $\sum_{j \neq i} x_j \neq \bar{T}$ and $x_i = 0$ otherwise. In other words, if individual i believes that all other group members as a whole will take just exactly the threshold \bar{T} , the best strategy for him is not to take any more. However, if he believes that all other group members as a whole will take too much or too little, the best strategy for him is to take. Nash equilibria in the threshold common resources game are just correspondent to those in the threshold public goods game. Specifically, we have first a complete free-riding Nash equilibrium in which $x_i = w$ for all i and thus $G = 0$. In this case the best response for $\sum_{j \neq i} x_j = \bar{G} - w$ is $x_i = w$ for all i . Second, we have some asymmetric pure strategy Nash

equilibria in which $\sum_j x_j = \bar{T}$. In this case, if individual i takes all of his entitlement, the best strategy for him is to remain a taker; and if individual i currently exploits nothing from the common pool, the best strategy for him is to leave his entire entitlement there. Third and the final, we have an infinite number of mixed strategy Nash equilibria in which individuals randomize the probabilities of exploiting and not exploiting such that the sum of the expected amount taken by all group members is exactly equal to \bar{T} .

If contributions are continuous, that is, $g_i \in [0, w]$, it is now less apparent to define the “pivotal” agent in the threshold public goods game. Any shortage below the threshold can be made up by more than one group member, and it is possible for more than one contributor to withdraw part of their current contributions if group contributions exceed the threshold. Nash equilibria of the threshold public goods game with continuous contributions, also solved by Cadsby and Maynes (1999), include the following. First of all, there is a complete free riding Nash equilibrium in which everyone contributes zero as long as $w < T$, since the best response for $\sum_{j \neq i} g_j = 0$ is $g_i = 0$ for all i . Second, we have a symmetric pure strategy Nash equilibrium in which every group member contributes $g_i = T/n$ if $T/n < w$ and $B > T/n$. Third, there are an infinite number of asymmetric pure strategy Nash equilibria in which group contributions satisfy $\sum_j g_j = T$. Fourth and the final, we have an infinite number of mixed strategy Nash equilibria in which individuals randomize the probabilities of all possible amounts of contributions such that the sum of the expected contributions made by all group members exactly reaches the threshold T .

We can also easily transform the above threshold public goods game into a threshold common resources game by letting \bar{G} be the initial size of the common source and $x_i \in [0, w]$ be individual i 's exploitation from the common resource. Nash equilibria in the common resources game can be found analogously. Briefly speaking, we first have a complete free-riding Nash equilibrium in which $x_i = w$ for all i . Another symmetric pure strategy Nash equilibrium is illustrated by $x_i = \bar{T}/n$ for all i . Third, there are also an infinite number of asymmetric pure strategy Nash equilibria in which $\sum_j x_j = \bar{T}$. And finally, we have an infinite number of asymmetric mixed strategy Nash equilibria in which group members randomize the probabilities of exploiting various amounts from the common resource such that the sum of the

expected amount exploited by all group members is exactly equal to \bar{T} .

3. EXPERIMENTAL DESIGN

We conduct two series of experiments, each series involving two conditions: the public good condition and the common resource condition. In one series of experiments subjects give to the public good or take from the common resource in a binary manner, and in the other giving and taking are continuous. Both public good and common resource conditions are each played in groups of five and groups of twenty, so that four experiments are involved in each series of experiments. Sixty subjects are used in all experiments of group size of twenty. Except the common resource experiment with binary contributions in which forty-five subjects show up, fifty subjects are used in all other experiments of group size of five, for a total of 435 subjects participating in this study.

Subjects are undergraduate students at National Taiwan University and National Chengchi University and all are inexperienced. 163 are males and 272 are females, and among these subjects 369 students are majoring in economics or economics related fields. The average earnings per subject are NT\$312. It takes about 80 minutes to finish one experiment, thereby the average hourly earnings per subject are about NT\$234, which is more than twice the part-time hourly wage rate for an undergraduate student in Taiwan.³

Subjects' Instructions, Earnings Report, and Decision Forms are handed out to each subject after he/she takes the seat.⁴ Subjects in each experiment play ten decision rounds and are randomly assigned their group numbers. Subjects are aware that group numbers remain unchanged over all ten rounds, but do not know which group they belong to. Except for the group numbers assigned to all subjects, all other parameters in the experiment, including group size, the size of the endowment in the public goods game (or the maximum amount of exploitation in the common resources game), total points invested in (or withdrawn from) the Public Account by all group members, and the payoff scheme, are known to all subjects.

³ The exchange rate between U.S. dollars and NT dollars was about 1:33 when these experiments were conducted.

⁴ Appendix 1 and Appendix 2 provide Subjects' Instructions, Earnings Report and a sample of Decision Form. Chinese translations are used in experiments.

In threshold public goods experiments with binary contributions, subjects each is endowed with 100 points per round. They are instructed to invest either 0 or 100 points to the Public Account. Points not invested in the Public Account will be left in the subject's own Private Account, and one point in the Private Account will earn the subject one point. In the experiment of group size of five, if three or more than three group members give 100 points to the Public Account, a bonus of 1500 points will be accumulated in the Public Account and will be shared equally by all group members. Thus, each group member will get a bonus of 300 points. However, if fewer than three subjects give to the Public Account, all group members will get no bonus and all points invested in the Public Account will be wasted. Each subject's earnings per round are the sum of the return from his or her Private Account and the bonus from the Public Account. Same threshold, that is, contributions made by at least three-fifths of group members, and same award are adopted in the experiment of group size of twenty. Specifically, if twelve or more than twelve group members give 100 points to the Public Account, a bonus of 6000 points will be accumulated in the Public Account and each group member will get a bonus of 300 points.

In threshold common resources experiments with binary contributions, each subject is endowed with zero point and is instructed to take either 0 or 100 points from the Public Account. Points taken from the Public Account will be invested in the subject's Private Account, and one point in the Private Account will earn the subject a return of one point. In the experiment of group size of five, 500 points are initially invested in the Public Account. If two or less than two subjects take 100 points from the Public Account, the Public Account will yield a bonus of 1500 points which will be shared equally by all group members. Thus, each group member will get a bonus of 300 points. However, if more than two subjects take from the Public Account, no bonus will be earned and all points left in the Public Account will be wasted. Similarly, in the experiment of group size of twenty, 2000 points are initially invested in the Public Account. If eight or less than eight subjects take 100 points from the Public Account, this account will accumulate a bonus of 6000 points and each group member will get a bonus of 300 points. Otherwise, the Public Account will be gone and all points left in this account will be wasted.

With continuous contributions, in threshold public goods experiments subjects are instructed to give any points between 0 and 100 to the Public Account, and in threshold common resources experiments subjects are instructed to take any points between 0 and 100 from the Public Account.

Same threshold and same award are used in experiments with continuous contributions. Namely, in the threshold public goods experiment of group size of five, if group contributions to the Public Account reach 300 or more than 300 points, each group member will get a bonus of 300 points. In the threshold common resources experiment of the same group size, if the total leftover in the Public Account remains at least 300 points, each group member will get a bonus of 300 points. Likewise, in the experiments of group size of twenty, if the threshold of 1200 points is reached (in the public goods experiment) or maintained (in the common resources experiment), each group member will get the same award of 300 points.

4. EXPERIMENTAL RESULTS

4.1. Comparing Cooperation Rates between Experiments

Table 1 illustrates the cooperation rate per round in the threshold public goods and common resources experiments. The notation B-PG-5 indicates the threshold public goods experiment of group size of five and with binary contribution mechanism. Notations for other experiments are explained analogously. The cooperation rate in the public goods experiments is defined as the total points contributed to the Public Account divided by the number of participants, and in the common resources experiments is defined as the total points left in the Public Account divided by the number of participants. We examine the difference between frames, between group sizes, and between contribution mechanisms by using t -test and Mann-Whitney rank-sum test. Table 2 reports the statistical results.

Notice first the effect of decision framing on cooperation. With binary contribution mechanism, the cooperation rates in all ten rounds in the threshold public goods experiment of group size of five are all higher than those in the threshold common resources experiment of the same group size. However, this trend cannot be found in experiments of group size of twenty. With continuous contribution mechanism and group size of five, except the first round the cooperation rate per round is higher in the threshold public goods experiment than in the common resources experiment. On the contrary, in experiments of group size of twenty, this trend is reversed that excluding the last round, cooperation rates are all higher in the common resources experiment than in the public goods experiment. The statistics in Table 2 also show that subjects in groups of five are more cooperative in the public goods experiments than in the common resources experiments, regardless of the contribution mechanism. Nonetheless, as

group size increases to twenty, the opposite result that cooperation is higher in the common resources experiment than in the public goods experiment is found when contributions are continuous, and no difference can be found when contributions are binary.

Now we look at how the size of group affects cooperation. In public goods experiments with binary contributions, cooperation rate per round is higher in the experiment of group size of five than in the experiment of group size of twenty, but the group size effect cannot be found in the common resources experiments with binary contributions. These results are also shown in Table 2. In public goods experiments with continuous contributions, the cooperation rate per round, except the last round, is higher in the experiment of group size of five than in the experiment of group size of twenty. On the contrary, in common resources experiments with continuous contributions, cooperation rates in all ten rounds are all higher in the experiment of group size of twenty than in the experiment of group size of five.

We then investigate how contribution mechanisms affect cooperation. Contribution methods have no effect on cooperation in both public goods experiments and common resources experiments when group size is five. However, as the group size grows to twenty, cooperation rates in public goods experiments are significantly higher in continuous contribution mechanism than in binary contribution mechanism. Continuous contributions also significantly raise cooperation in the common resources experiments when group size is twenty, though cooperation rates in round 6 and round 7 are slightly lower with continuous contributions than with binary contributions.

Because framing effect is found in most experiments, but not in all experiments, it may be interesting to ask whether decision framing causes the differences in cooperation between the threshold public goods and common resources experiments, or group sizes and contribution methods play a more important role. We explore the differences in cooperation between the threshold public goods and common resources experiments by using the Analysis of Variance (ANOVA) and report the results in Table 3. We first observe that decision framing has no significant effect on the differences in cooperation between these two threshold games. In contrast, effects of group size and contribution mechanism on cooperation are significant. Cooperation is significantly higher in groups of five than in groups of twenty, and is significantly higher in continuous contribution mechanism than in binary contribution mechanism.

We then ask whether effects of group size and contribution mechanism help explain the

differences in cooperation between the threshold public goods and common resources experiments. Observing from Table 3, the cross-effects between frames and group sizes and between group sizes and contribution mechanisms are significant, but not between frames and contribution mechanisms. The cross-effect between frames, group sizes, and contribution mechanisms is not significant, either. Therefore, we conjecture that the significance of differences in cooperation between the threshold public goods and common resources experiments may be mainly attributed to continuous contribution mechanism and small group size.

4.2. Comparing Complete Free-Riding between Experiments

It may be interesting to ask how many subjects play the complete free-riding strategy. Table 4 lists the percent of subjects contributing zero to the Public Account in each experiment and Table 5 reports the statistical results. As shown in Table 4 and Table 5, the complete free-riding incentive is significantly higher in the common resources experiments than in the public goods experiments when group size is five, regardless of the contribution mechanism. If we enlarge the group size to twenty, starting the third round this result is reversed in experiments with binary contributions, but the difference between the threshold public goods experiment and the threshold common resources experiment is not significant. However, the opposite result is found when contributions are continuous that complete free-riding is significantly higher in the public goods experiment than in the common resources experiment.

If looking across different group sizes, when contributions are binary, the complete free-riding incentive is significantly higher in groups of twenty than in groups of five in public goods experiments. Though subjects in groups of twenty also have a stronger complete free-riding incentive than subjects in groups of five in the common resources experiment with binary contributions, the difference is not significant. Larger size of groups still provides subjects stronger incentives to free ride in the public goods experiments with continuous contributions, but surprisingly, complete free-riding is significantly higher in groups of five than in groups of twenty in the common resources experiments with continuous contributions.

Regarding the effect of contribution methods on subjects' incentives to free ride, we can see that continuous contribution mechanism greatly alleviate complete free-riding in both threshold public goods and common resources experiments, in spite of the group size.

4.3. Fraction of Groups Playing the Complete Free-Riding Nash Equilibrium and Threshold Nash Equilibria

Table 6 shows the fraction of groups playing the complete free-riding Nash equilibrium and Table 7 reports the statistical results. Notice first that the complete free-riding Nash equilibrium never shows up in four out of eight experiments, and even if it shows up in the rest four experiments, the frequency is quite low. Second, as reported in Table 7, though the frequency of attaining the complete free-riding Nash equilibrium is significantly different between C-PG-5 and C-COM-5, and between C-COM-5 and C-COM-20 by using t -test, we can not find significant difference between any two compared experiments by using the Mann-Whitney test.

Table 8 lists the fraction of groups whose group contributions exactly match the threshold. We report the statistical analysis associated with the difference between two compared experiments in Table 9. The first thing to note is that as compared to the complete free-riding Nash equilibrium, the threshold Nash equilibria are reached more often in all experiments. Second, we observe that decision framing has no significant effect on reaching the threshold Nash equilibria. Fractions of groups playing the threshold Nash equilibria in the public goods experiments are not significantly different from that in the common resources experiments, regardless of the group sizes and contribution mechanisms. Third, smaller group size significantly helps subjects to play the threshold Nash equilibria when contributions are binary. Though the threshold Nash equilibria are also easier to be attained in groups of five than in groups of twenty when contributions are continuous, this effect is significant only in the common resources experiments. Finally, though binary contribution mechanism is easier to induce group members to play the threshold Nash equilibria, in both public goods and common resources experiments and in both sizes of five and twenty, this effect is significant only in the public goods experiments of group size of five.

5. CONCLUSIONS

This paper examines cooperation in threshold public goods and common resources games by considering different sizes of groups and contribution mechanisms. Our main findings are as follows. First, our experimental evidence shows that subjects' cooperative behavior is significantly different between the threshold public goods and common resources experiments when group size is small and when contributions are continuous. No significant difference

between these two types of games can be found in large groups with binary contributions. Second, continuous contribution mechanism greatly raises cooperation in both threshold public goods and common resources experiments when group size is large, but has no effect when group size is small. Third, continuous contribution mechanism greatly alleviates the incentive of complete free-riding in both threshold public goods and common resources experiments, regardless of the group size. Finally, except in the common resources experiments of group size of five, the complete free-riding Nash equilibrium seldom shows up, and the threshold Nash equilibria are reached more often in all experiments than the complete free-riding Nash equilibrium.

TABLE 1

Cooperation Rate Per Round (in %)											
Experiment	Round										Average
	1	2	3	4	5	6	7	8	9	10	
B-PG-5	46.00	60.00	54.00	46.00	48.00	56.00	58.00	52.00	50.00	44.00	51.40
B-COM-5	37.78	48.89	51.11	40.00	35.56	37.78	46.67	42.22	37.78	33.33	41.11
B-PG-20	40.00	33.33	18.33	21.67	23.33	26.67	30.00	36.67	28.33	16.67	27.50
B-COM-20	23.33	26.67	28.33	25.00	40.00	60.00	55.00	38.33	36.67	21.67	35.50
C-PG-5	48.50	53.20	56.12	58.30	59.30	54.92	55.92	53.44	56.12	46.74	54.26
C-COM-5	49.76	50.90	51.10	42.06	40.60	39.40	41.40	42.00	37.10	30.60	42.49
C-PG-20	47.42	43.42	42.50	40.17	40.08	45.67	48.08	46.00	46.50	51.33	45.12
C-COM-20	55.65	55.10	54.42	53.35	55.45	57.22	54.30	49.35	49.55	42.23	52.66

TABLE 2

Differences in Cooperation between Two Relevant Experiments			
Compared Two Experiments		Z-test	Mann-Whitney Test
B-PG-5/B-COM-5	(Figure 1-a)	4.015*	88*
B-PG-20/B-COM-20	(Figure 1-b)	-1.647	33
C-PG-5/C-COM-5	(Figure 1-c)	4.865*	94*
C-PG-20/C-COM-20	(Figure 1-d)	-4.172*	10*
B-PG-5/B-PG-20	(Figure 1-e)	7.981*	100*
B-COM-5/B-COM-20	(Figure 1-f)	1.219	67.5
C-PG-5/C-PG-20	(Figure 1-g)	5.391*	96*
C-COM-5/C-COM-20	(Figure 1-h)	-4.070*	9*
B-PG-5/C-PG-5	(Figure 1-i)	-1.329	33
B-COM-5/C-COM-5	(Figure 1-j)	-0.495	42
B-PG-20/C-PG-20	(Figure 1-k)	-6.555*	0*
B-COM-20/C-COM-20	(Figure 1-l)	-3.872*	16*

* Significant at 5% significance level. The critical value for the t -statistic at 5% significance level is ± 2.101 , and the critical values of the two-sided test of Mann-Whitney at 5% significance level are 24 and 76.

TABLE 3
Effects of Frames, Group Sizes, and Contribution Mechanisms on Cooperation by Using
Analysis of Variance (ANOVA)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	<i>F</i> -statistic
Frame (A)	52.939	1	52.939	1.078
Group Size (B)	1013.945	1	1013.945	20.650*
Contribution Mechanism (C)	1902.732	1	1902.732	38.750*
AB	1766.993	1	1766.993	35.986*
AC	4.657	1	4.657	0.095
BC	1165.987	1	1165.987	23.746*
ABC	1.301	1	1.301	0.026
Error	3535.380	72	49.102	
Total	9443.934	79		

* Significant at the significance level 0.05. The critical value for the *F*-statistic of the *F*-test at the significance level 0.05 is about 3.973.

TABLE 4
Percent of Subjects Contributing Zero to the Public Account

Experiment	Round										Average
	1	2	3	4	5	6	7	8	9	10	
B-PG-5	54.00	40.00	46.00	54.00	52.00	44.00	42.00	48.00	50.00	56.00	48.60
B-COM-5	62.22	51.11	48.89	60.00	64.44	62.22	53.33	57.78	62.22	66.67	58.89
B-PG-20	60.00	66.67	81.67	78.33	76.67	73.33	70.00	63.33	71.67	83.33	72.50
B-COM-20	76.67	73.33	71.67	75.00	60.00	40.00	45.00	61.67	63.33	78.33	64.50
C-PG-5	14.00	10.00	16.00	10.00	6.00	10.00	12.00	14.00	14.00	24.00	13.00
C-COM-5	20.00	20.00	24.00	32.00	38.00	40.00	40.00	36.00	44.00	54.00	34.80
C-PG-20	10.00	20.00	23.33	28.33	30.00	28.33	30.00	28.33	26.67	26.67	25.17
C-COM-20	3.33	6.67	13.33	15.00	8.33	11.67	18.33	23.33	20.00	26.67	14.67

TABLE 5
Comparing Complete Free-Riding in Two Relevant Experiments

Compared Two Experiments		Z-test	Mann-Whitney Test
B-PG-5/B-COM-5	(Figure 2-a)	-4.015*	12*
B-PG-20/B-COM-20	(Figure 2-b)	1.655	67.5
C-PG-5/C-COM-5	(Figure 2-c)	-5.755*	2.5*
C-PG-20/C-COM-20	(Figure 2-d)	3.425*	88*
B-PG-5/B-PG-20	(Figure 2-e)	-7.968*	0*
B-COM-5/B-COM-20	(Figure 2-f)	-1.219	32.5
C-PG-5/C-PG-20	(Figure 2-g)	-4.915*	9.5*
C-COM-5/C-COM-20	(Figure 2-h)	4.796*	94*
B-PG-5/C-PG-5	(Figure 2-i)	15.377*	100*
B-COM-5/C-COM-5	(Figure 2-j)	6.107*	97*
B-PG-20/C-PG-20	(Figure 2-k)	15.135*	100*
B-COM-20/C-COM-20	(Figure 2-l)	10.332*	100*

* Significant at 5% significance level. The critical value for the t -statistic at 5% significance level is ± 2.101 , and the critical values of the two-sided test of Mann-Whitney at 5% significance level are 24 and 76.

TABLE 6
Fraction of Groups Playing the Complete Free-Riding Nash Equilibrium

Experiment	Round										Average
	1	2	3	4	5	6	7	8	9	10	
B-PG-5	0/10	0/10	0/10	1/10	0/10	0/10	0/10	0/10	0/10	1/10	0.02
B-COM-5	0/9	0/9	0/9	1/9	2/9	2/9	0/9	0/9	0/9	3/9	0.09
B-PG-20	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	1/3	0/3	0.03
B-COM-20	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0.00
C-PG-5	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0/10	0.00
C-COM-5	0/10	0/10	0/10	1/10	1/10	1/10	0/10	0/10	2/10	4/10	0.09
C-PG-20	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0.00
C-COM-20	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0.00

TABLE 7
Comparing Fraction of Groups Playing Complete Free-Riding Nash Equilibrium in Two Experiments

Compared Two Experiments		<i>Z</i> -test	Mann-Whitney Test
B-PG-5/B-COM-5	(Figure 3-a)	-1.165	42
B-PG-20/B-COM-20	(Figure 3-b)	1.464	60
C-PG-5/C-COM-5	(Figure 3-c)	-2.212*	25
C-PG-20/C-COM-20	(Figure 3-d)	NA	NA
B-PG-5/B-PG-20	(Figure 3-e)	-0.884	48
B-COM-5/B-COM-20	(Figure 3-f)	1.765	65
C-PG-5/C-PG-20	(Figure 3-g)	NA	NA
C-COM-5/C-COM-20	(Figure 3-h)	2.212*	75
B-PG-5/C-PG-5	(Figure 3-i)	1.500	40
B-COM-5/C-COM-5	(Figure 3-j)	-0.420	43.5
B-PG-20/C-PG-20	(Figure 3-k)	1.464	60
B-COM-20/C-COM-20	(Figure 3-l)	NA	NA

* Significant at 5% significance level. The critical value for the *t*-statistic at 5% significance level is ± 2.101 , and the critical values of the two-sided test of Mann-Whitney at 5% significance level are 24 and 76. NA is the abbreviation of “not available.”

TABLE 8
Fraction of Groups Matching the Threshold Nash Equilibria

Experiment	Round										Average
	1	2	3	4	5	6	7	8	9	10	
B-PG-5	3/10	3/10	5/10	2/10	4/10	3/10	4/10	6/10	3/10	1/10	0.34
B-COM-5	1/9	4/9	3/9	2/9	3/9	2/9	3/9	4/9	3/9	1/9	0.29
B-PG-20	0/3	0/3	0/3	0/3	0/3	1/3	0/3	1/3	0/3	0/3	0.07
B-COM-20	0/3	0/3	0/3	0/3	0/3	1/3	1/3	1/3	0/3	0/3	0.10
C-PG-5	0/10	1/10	0/10	2/10	0/10	2/10	1/10	2/10	0/10	2/10	0.10
C-COM-5	1/10	0/10	0/10	3/10	4/10	1/10	2/10	3/10	3/10	3/10	0.20
C-PG-20	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	1/3	0/3	0.03
C-COM-20	0/3	0/3	1/3	0/3	0/3	0/3	0/3	0/3	0/3	0/3	0.03

TABLE 9
Comparing Fraction of Groups Playing Threshold Nash Equilibria in Two Experiments

Compared Two Experiments		<i>Z</i> -test	Mann-Whitney Test
B-PG-5/B-COM-5	(Figure 4-a)	0.868	54
B-PG-20/B-COM-20	(Figure 4-b)	-0.493	45
C-PG-5/C-COM-5	(Figure 4-c)	-1.861	28
C-PG-20/C-COM-20	(Figure 4-d)	0.000	50
B-PG-5/B-PG-20	(Figure 4-e)	4.311*	88*
B-COM-5/B-COM-20	(Figure 4-f)	2.979*	82*
C-PG-5/C-PG-20	(Figure 4-g)	1.491	72
C-COM-5/C-COM-20	(Figure 4-h)	2.988*	82*
B-PG-5/C-PG-5	(Figure 4-i)	4.431*	93*
B-COM-5/C-COM-5	(Figure 4-j)	1.518	74
B-PG-20/C-PG-20	(Figure 4-k)	0.600	47
B-COM-20/C-COM-20	(Figure 4-l)	1.095	60

* Significant at 5% significance level. The critical value for the *t*-statistic at 5% significance level is ± 2.101 , and the critical values of the two-sided test of Mann-Whitney at 5% significance level are 24 and 76.

APPENDIX 1: SUBJECTS' INSTRUCTIONS

(for groups of five and binary contribution)The Public Good Condition

Subjects' Instructions

Welcome

This experiment is a study about individual and collective decision making. You may earn a substantial amount of money if you follow the instructions and make your decisions carefully. The money you earn will be paid, in cash, to you at the end of the experiment. A research institute provides the funds for this experiment.

The Environment and Your Decisions

In this experiment you will make a series of **ten** investment decisions. Each decision you make will result in a *cash return* depending on the decisions that you and the other subjects in your group make. The sum of the cash return you earn in each decision round will be your total cash return.

You and the other subjects are **randomly** assigned to groups of **five**. The composition of your group **will never** change, and you will never know who are the other four members in your group. Your earnings will be represented by “points” during the experiment. **Five** points will be transformed to NT\$1 at the end of the experiment. Each subject is endowed with **100** points per round and decides to invest the whole **100** points in either the Private Account or the Public Account. Each subject has his/her own Private Account, but all members in the same group share the Public Account together. Therefore, returns from the Private Account will only benefit self and returns from the Public Account will benefit all group members equally.

In each round you will make a decision between two choices: investing **100** points in the Private Account and investing **100** points in the Public Account, which are also listed on the Decision Forms. Notice that investing **100** points in the Private Account is equivalent to investing 0 point in the Public Account; likewise, investing **100** points in the Public Account is equivalent to investing 0 point in the Private Account. Please mark “√” on the top of the choice that you decide and turn in the Decision Form to the assistant. After all subjects having turned in their Decision Forms, the experimenter will key in all subjects' decisions, then the computer

will calculate your earnings and print out relevant information this round. The information includes: the round number, your subject number, your own decision, number of members in your group investing in the Public Account, your earnings from the Private Account and the Public Account, and your total earnings this round. You may record the information correspondingly on your Earnings Report. The above procedure will repeat for all decision rounds. **NOTICE THAT YOUR DECISIONS AND EARNINGS WILL REMAIN SECRET, AND NO COMMUNICATION WITH OTHER PARTICIPANTS IS ALLOWED.**

The Private Account

If you invest the 100 points in the Private Account, you earn 100 points and the other four group members earn nothing from your investment. Similarly, you earn nothing from other members' investments in their own Private Accounts.

Example 1. Suppose that you invested 100 points in the Private Account. Your earnings from the Private Account would be 100 points.

Example 2. Suppose that you invested 100 point in the Public Account. Your earning from the Private Account would be 0 point.

The Public Account

Your earnings from the Public Account depend on the total points that you and the other four members in your group invest in this Account. Each member in your group will earn 300 points from the Public Account if the total points accumulated in the Public Account reach or exceed 300 points. However, if the total points accumulated in the Public Account are less than 300 points, everyone in your group gets zero point from this account.

Example 1. Suppose that you invested 100 points in the Public Account and that the Public Account was accumulated 500 points. Your earnings from the Public Account would be 300 points. The other four members of your group would also get 300 points.

Example 2. Suppose that you invested 100 points in the Public Account and that the Public Account was accumulated 300 points. Your earnings from the Public Account would be 300 points. The other four members of your group would also get 300 points.

Example 3. Suppose that you invested 100 points in the Public Account and that the Public Account was accumulated 200 points. Your earning from the Public Account would be 0 point.

The other **four** members of your group would also get 0 point.

Example 4. Suppose that you invested 0 point in the Public Account and that the Public Account was accumulated **400** points. Your earnings from the Public Account would be **300** points. The other **four** members of your group would also get **300** points.

Example 5. Suppose that you invested 0 point in the Public Account and that the Public Account was accumulated **300** points. Your earnings from the Public Account would be **300** points. The other **four** members of your group would also get **300** points.

Example 6. Suppose that you invested 0 point in the Public Account and that the Public Account was accumulated **100** points. Your earning from the Public Account would be 0 point. The other **four** members of your group would also get 0 point.

Your Earnings Per Round

Your earnings per round will be the sum of earnings from your Private Account and earnings from the Public Account.

Example 1. Suppose that you invested **100** points in the Private Account and that the Public Account was accumulated **400** points. Then your earnings are **400** points.

Example 2. Suppose that you invested **100** points in the Public Account and that the Public Account was accumulated **200** points. Then your earning is **0** point.

WE NOW START THE FIRST ROUND.

The Common Resource Condition

Subjects' Instructions

Welcome

This experiment is a study about individual and collective decision making. You may earn a substantial amount of money if you follow the instructions and make your decisions carefully. The money you earn will be paid, in cash, to you at the end of the experiment. A research institute provides the funds for this experiment.

The Environment and Your Decisions

In this experiment you will make a series of ten decisions. Each decision you make will result in a *cash return* depending on the decisions that you and the other subjects in your group make. The sum of the cash return you earn in each decision round will be your total cash return.

You and the other subjects are **randomly** assigned to groups of **five**. The composition of your group **will never** change, and you will never know who are the other four members in your group. Your earnings will be represented by “points” during the experiment. **Five** points will be transformed to NT\$1 at the end of the experiment. Each subject has his/her own Private Account, but all members in the same group share the Public Account together. Therefore, returns from the Private Account will only benefit self and returns from the Public Account will benefit all group members equally.

There are **500** points in the Public Account at the beginning of each decision round. In each round you will make a decision between two choices: withdrawing **100** points from the Public Account and withdrawing 0 point from the Public Account, which are also listed on the Decision Forms. If you withdrew **100** points from the Public Account, your Private Account would be increased by **100** points and the Public Account would be reduced by **100** points. Please mark “✓” on the top of the choice that you decide and turn in the Decision Form to the assistant. After all subjects having turned in their Decision Forms, the experimenter will key in all subjects' decisions, then the computer will calculate your earnings and print out relevant information this round. The information includes: the round number, your subject number, your

own decision, number of members in your group withdrawing from the Public Account, your earnings from the Private Account and the Public Account, and your total earnings this round. You may record the information correspondingly on your Earnings Report. The above procedure will repeat for all decision rounds. **NOTICE THAT YOUR DECISIONS AND EARNINGS WILL REMAIN SECRET, AND NO COMMUNICATION WITH OTHER PARTICIPANTS IS ALLOWED.**

The Private Account

If you withdraw 100 points from the Public Account, you earn 100 points from your Private Account, and the Public Account is reduced by 100 points.

Example 1. Suppose that you withdrew 100 points from the Public Account. Your earnings from the Private Account would be 100 points.

Example 2. Suppose that you withdrew 0 point from the Public Account. Your earning from the Private Account would be 0 point.

The Public Account

Your earnings from the Public Account depend on the total points that you and the other four group members withdraw from this Account. Each member in your group will earn 300 points from the Public Account if the total leftovers are at least or more than 300 points. However, if the total leftovers are below 300 points, everyone in your group gets zero point from the Public Account.

Example 1. Suppose that you withdrew 100 points from the Public Account and that the total leftovers in the Public Account were 400 points. Your earnings from the Public Account would be 300 points. The other four members of your group would also get 300 points.

Example 2. Suppose that you withdrew 100 points from the Public Account and that the total leftovers in the Public Account were 300 points. Your earnings from the Public Account would be 300 points. The other four members of your group would also get 300 points.

Example 3. Suppose that you withdrew 100 points from the Public Account and that the total leftovers in the Public Account were 100 points. Your earning from the Public Account would be 0 point. The other four members of your group would also get 0 point.

Example 4. Suppose that you withdrew 0 point from the Public Account and that the total

leftovers in the Public Account were 300 points. Your earnings from the Public Account would be 300 points. The other four members of your group would also get 300 points.

Example 5. Suppose that you withdrew 0 point from the Public Account and that the total leftovers in the Public Account were 200 points. Your earning from the Public Account would be 0 point. The other four members of your group would also get 0 point.

Example 6. Suppose that you withdrew 0 point from the Public Account and that the total leftover in the Public Account was 100 point. Your earning from the Public Account would be 0 point. The other four members of your group would also get 0 point.

Your Earnings per Round

Your earnings per round will be the sum of earnings from your Private Account and earnings from the Public Account.

Example 1. Suppose that you withdrew 100 points from the Public Account and that the total leftovers in this account were 400 points. Your earnings would be 400 points.

Example 2. Suppose that you withdrew 0 point from the Public Account and that the total leftovers in this account were 200 points. Your earning would be 0 point.

WE NOW START THE FIRST ROUND.

APPENDIX 2: DECISION FORM AND EARNINGS REPORT

(for groups of five and binary contribution)

Decision Form

The public good condition:

Subject number: _____

Invest 100 points in Private Account	Invest 100 points in Public Account

The common resource condition:

Subject number: _____

Withdraw 100 points from the Public Account	Withdraw 0 points from the Public Account

Earnings Report

The public good condition:

Subject number: _____

round		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Your Decision (mark ✓)	Invest 100 points in Private Account										
	Invest 100 points in Public Account										
Number of group members investing 100 points in the Public											
Earnings from your Private Account											
Earnings from the Public Account											
Earnings per round											

The common resource condition:

Subject number: _____

round		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Your Decision (mark ✓)	Withdraw 100 points from Public Account										
	Withdraw 0 point from Public Account										
Number of group members withdrawing 100 points from the											
Earnings from your Private Account											
Earnings from the Public Account											
Earnings per round											

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