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It Works in Practice. Does it Work in Theory?

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ABSTRACT

In 1968, Hardin argued that all commonly-owned resources would tragically be depleted unless private ownership was granted. There are many case studies which prove Hardin wrong. Common-pool resources have been managed with success. However, this success does not imply (as some believe) that communal ownership and management "works" and is the appropriate management style for all resources. At the very least, the word "works" needs definition.

The Japanese village of Hirano used a lottery mechanism to distribute winter fodder gathered on village-owned land. It is true that the fodder gathering and distribution system worked — the villagers used this system from the 1600's to the 1950's. But, the question remains; was the mechanism effective in curtailing excessive harvesting from the commons? The results of this economic experiment suggest that the lottery mechanism greatly enhances the efficient use of the resource by reducing individual incentives to over-appropriate. Despite the effectiveness of this mechanism, it is not the case that individuals act in the manner suggested by economic theory. Further research is necessary to understand how individuals operate in this environment.

Keywords: Mechanism Design, Game Theory, Collective Action, Experiment

JEL Classification: D7, C7

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I. Introduction

Common-pool resources are one example of collective action games. The equilibrium of these games involves lower aggregate utility than that achievable through cooperative group action.[1] In public good environments, people voluntarily contribute less than the optimal amount because they free-ride upon each other. Common-pool resources are similar. Because users tend to ignore costs imposed on others, over-appropriation results and the commons are degraded.

Data gathered by social scientists of all types have repeatedly shown that the degradation of the commons is not necessarily as widespread as theorists once believed. Many successes exist, or have existed. However, failures also abound, and in some cases, the tragedy has been sorely felt (see Bromley, 1992, Feeny et al., 1990, and Feeny et al., 1996 for examples of successes and failures). What differentiates the successes from the failures?

The answers to this question are numerous, but they can be grouped into three broad categories. First, it is well known that individuals are more cooperative than economists have predicted.[2] For instance, in public good experiments, some subjects voluntarily contribute a positive amount to public goods when payoffs are linear and economists (using the Nash equilibrium concept) would predict that they would contribute zero (Isaac and Walker, 1988a, b). Nevertheless, this falls short of the 100% contribution that maximizes social payoff. The results are similar in experiments in which Nash and Pareto solutions are both interior (Chan, et al., 1996, 1998). There is evidence that Hardin's "Tragedy of the Commons" (1968) is not as tragic in practice as it is on paper. Subjects often appropriate less from the common pool than what the Nash equilibrium would predict (Ostrom, et al., 1994; Moir, 1997), but empirical results are still less than socially optimal.

Second, communication and institutional devices (e.g. sanctioning and monitoring) alter people's behaviour.[3] Monitoring and sanctioning generally increase cooperation (Ostrom et al., 1994; Moir, 1997). Face-to-face communication, even when agreements are not enforced, greatly enhances cooperation (Isaac and Walker, 1988b; Ostrom et al., 1994; Chan et al., 1998).

Third, mechanisms have been designed to alter people's incentives so that they are more likely to behave in a way that makes the social outcome achievable and maintainable as an equilibrium. There are many examples of mechanism which have been implemented to varying degrees of success.

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[1] Of course, this ignores games of coordination.

[2] For surveys see Camerer (1997) for a discussion of behavioural game theory and Ledyard (1995) for a survey of the results from collective action experiments.

[3] Here I consider mechanisms separately from communication and institutional devices, although they are closely related. Mechanisms operate by directly altering individual incentives while communication and institutional devices often operate in a less direct manner.

The evolution of social norms can make seemingly irrational actions rational when viewed inside a cultural context (e.g. Frank, 1985). Tithing a percentage of resources, which was viewed in some cultures as almost mandatory, limits the private benefits from captured resources and also provides for the public good. By placing technological limitations upon resource users, the productive capabilities of users can be limited. Users can form cooperatives to sell the harvested product on the market, thereby ensuring that restricted resource appropriation is in the interest of profit-maximizing users. Lottery assignment and other randomizing techniques have also been used, and are the focus of this study.

There are also examples of mechanisms which have been proposed by theorists, but, other than in laboratory environments, are not generally used. In order to achieve optimal voluntary contributions to public goods, the Lindahl mechanism (1919), the Groves-Ledyard mechanism (1977), the Tideman-Tullock mechanism (1976), and Walker's (1981) variant of the Lindahl mechanism were designed to force users to reveal their true demand. In cases where these mechanism designs have been tested (for example Smith, 1979), it is not always the case that people have behaved in the predicted manner. Loehman and Rassenti (1997) have also designed and tested a cost sharing mechanism which shows some promise. In all of these cases, the existence of a sophisticated ruler or government — one that can 1) solve for and implement the updating necessary to send signals back to the potential contributors, and 2) manage any voting that is necessary — is assumed.

Although these mechanisms may be effective in shifting behaviour towards a collective solution, their complexity may be so great that the transaction costs associated with implementation imply negligible or negative net gains. Many of these mechanisms require intermediate solutions, involving complex calculations, which are reported back to the contributors. Thus, complex mechanisms often require a computer and a skilled operator. Moreover, complex mechanisms require information from users who may find such information costly to produce (e.g. they may have to attend a meeting which would take them away from work). In other words, there are non-negligible costs associated with complex mechanisms.

This paper reports on a very simple (i.e. low cost) mechanism which was used to curtail excessive winter fodder harvesting upon commonly owned land in Japan. The history of the mechanism is described in section II. In section III the experiment design and hypotheses are discussed. Results are contained in section IV and conclusions follow in section V.

II. A Simple Mechanism

Simple mechanisms generally have low implementation costs (Feeny, 1998). Moreover, implementation is easy, because the mechanism is easily understood. In this study, a lottery is used to distribute the resources extracted from a commonly owned resource. Although it is necessary to have a government to enforce the rules, the role the government plays is much smaller than in the mechanisms mentioned above.

The lottery rule has been used to determine the right to fishing grounds in Alanya, Turkey (Berkes, 1992: 170), to determine the timing of access to irrigation waters in Valencia, Spain (Ostrom, 1990: 73), and in Newfoundland, until the fishery collapse, cod trap locations were distributed using a lottery scheme.[4] However, the particular rule I will test is described in McKean (1992: 63-98). Hirano is one of three Japanese villages mentioned in McKean's study. It has a long history, extending from the Tokugawa shogunate (1603 to 1868) and lasting until at least World War II, of effectively managing commonly-owned resources. Winter fodder was gathered from village-owned land (pp. 78-79). After cutting, drying and bundling the fodder, bundles were divided into even clusters, one for each family. These bundles were then distributed to the families using a lottery system. There are a number of reasons for such a distribution system:

- i) It prevents *competitive* cutting, thereby removing the problem of 'rule by capture'.[5]
- ii) It assures relatively equal amounts of fodder per household.
- iii) Because the fodder varied in quality,
  - a) it avoided bad feelings in the village, and
  - b) it avoided *competitive* bundling.
- iv) In a repeated game framework,
  - a) it creates an incentive to conform to the norms of the community because of the equalizing properties of the mechanism, and
  - b) it creates an immediate version of the tit-for-tat strategy because one may be punished with one's own small low-quality bundle, or may not be rewarded with one's own large high-quality bundle.

Lottery assignment was, and is viewed as a 'fair' system (see ii and iii.a above). It captures the essence of Rawls' 'Veil of Ignorance'.[6] Because it is viewed as fair, individuals are likely to conform to the rules with little persuasion and low transaction cost. Moreover, by curtailing competition over ownership (see i and iii.b above), the lottery system "solves" the collective action problem. Like other mechanisms, and especially the theoretical mechanisms mentioned previously, the lottery severs the connection between individual behaviour and the resulting outcome — individuals no longer gain from being uncooperative.

Simple examples of variants of this mechanism exist, and anecdotal evidence suggests that they are effective. For instance, when there was one piece of cake left, my mother instituted the following rule to prevent fighting between my brother and myself: one person cuts, and the other gets the first selection of the two pieces. Although we usually found reasons to fight, who got the best

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[4] Stephan Schott (University of Guelph) informed me of this application of the lottery mechanism. Although the fishers viewed the scheme as fair, it did not necessarily curtail fishing effort. However, it may have been more effective had the lottery been used to distribute the catch and not the right to a particular fishing location.

[5] The 'rule of capture' states that the individual who captures the resource owns it. Note that one solution to this problem is to permit a limited amount of time for each family to harvest on the commons. This mechanism may lead to a race to cut the most fodder and could result in significant environmental damage. Lottery assignment, an alternative mechanism, would not lead to such a race.

[6] Rawls (1971: 136-142) argued that from behind a veil of ignorance about one's own abilities and resources in the future, a rational individual would choose a fair, or just, distribution.

piece of cake was not one of them. Anecdotal evidence is not usually sufficient in a scientific world. Could we have reached a similar solution without a rule imposed by a parent? Ostrom, in outlining features common to effectively managed common-pool resources, states,

> I do not claim that the institutions devised in these settings are in any sense "optimal". In fact, given the high levels of uncertainty involved and the difficulty of measuring benefits and costs, it would be extremely difficult to obtain a meaningful measure of optimality.
>
> (1990: 59-60)

However, if the mechanism can be implemented in the laboratory, then an economic experiment can give some indication of the effectiveness of a rule, device or mechanism in achieving a socially optimal outcome.

III. Design and Hypotheses

The lottery mechanism was tested in a public good environment with voluntary contributions. Not only is this a collective action game, it can be thought of as a method of maintaining a common-pool resource such as air quality. There are, however, fundamental differences between public good and common-pool resource environments (see Ledyard, 1995 for discussion). Still, the simple prediction of the lottery scheme is that it will increase cooperation in either environment.

Translating the mechanism for use in the lab is quite straightforward, and also reveals the logic of the lottery scheme. Instead of making voluntary contributions to a public goods, suppose people (potentially) benefitting from a public good write down on a piece of paper a fraction of income that they would like to see contributed towards public good provision. These pieces of paper are then placed in a hat and randomly distributed to all potential users of the public good, who must then contribute according to the fraction specified on the slip of paper they receive. It no longer pays to free-ride, as someone else may benefit if they receive an unusually low fraction.[7]

Suppose a number of identical individuals attempt to maximize their payoff (π_i), which depends upon their investment in a private good (x_i) and a public good (g_i) subject to standard non-negativity constraints, and an income (w_i) constraint. In functional form, this is expressed as,

$$\max \pi_i = a(x_i + G + \tau x_i G) \text{ subject to } w_i = x_i + g_i \qquad \textbf{(1)}$$

where, $G=\Sigma g_i$ and a and τ are payoff scaling parameters. In particular τ was selected such that the individual contributions to the public good at the symmetric Nash and social optimum did not equal ½ of the endowment (w_i) as this is a natural focal point for subjects to choose.

From (1) the reaction function

$$g_i^R = \max[\frac{w_i - G_{-i}}{2},\ 0],$$

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[7] In this analysis, it is simplest to assume that all individuals are alike in terms of preferences and wealth. I suspect that as long as utility from investing in the public good (or the resource gathered from a common-pool resource) is additively separable from private investment, then the technique will work. However, the particular payoff function used in this experiment does not exhibit additive separability so, in some sense the problem is more difficult to solve.

can be derived, where G_{-i} is the sum of contributions to the public good made by individuals other than i. Assuming identical individuals act alike, then the Nash equilibrium contribution is

$$g_i^{\,N} = \frac{w_i}{2+(n-1)}.$$

If a social planner attempts to maximize the sum of payoffs, then total contributions to the public good would be,

$$G^{\,S} = \frac{(n-1)+\tau W}{2\tau}.$$

Symmetric individual contributions can be calculated by dividing the group contribution by n. Notice that the payoff scaling factor (a) should not affect individual choices. Moreover, τ does not affect the actions of a self-interested individual. The parameters used in this experiment are summarized in Table 1. The contribution predictions, associated payoffs, and shares are summarized in Table 2.

In the standard voluntary contributions public goods experiment, individuals select a share of their own income to devote to the public good. Now suppose an individual submits a share (s_i) to a council that then randomly distributes the shares among those benefitting from the public good, and further, requires them to contribute that portion of their income to the public good. The intuition in this case is quite simple. Because individuals cannot guarantee that they will benefit from their own free-riding, it is no longer in their best interest to do so.

Let the average share of income to be contributed be expressed as $\frac{\sum_{k=1}^{n} s_k}{n}$ so that the expected individual and group contributions are $\frac{\sum_{k=1}^{n} s_k}{n} w_i$ and $\frac{\sum_{k=1}^{n} s_k}{n} \sum_{k=1}^{n} w_k$ respectively. In this case, the expected payoff to subject i is

$$E\pi_i = a[(w_i - \frac{\Sigma s_k}{n} w_i) + (\frac{\Sigma s_k}{n} \Sigma w_k) + \tau(w_i - \frac{\Sigma s_k}{n} w_i)(\frac{\Sigma s_k}{n} \Sigma w_k)],$$

which is maximized by selecting s_i. Solving this maximization problem leads to the reaction function

$$s_i^{\,R} = \frac{n\sum_{j\neq i} w_j}{2\tau(\Sigma w_k) w_i} + \frac{n}{2} - \sum_{j\neq i} s_j,$$

which, if all agents act alike, results in the Nash equilibrium,

$$s_i^{\,N} = \frac{\sum\limits_{j \neq i} w_j}{2\tau(\sum w_k) w_i} + \frac{1}{2}.$$

Using the parameters in Table 1, the Nash equilibrium share in the lottery treatment is the same as the share of income contributed to the public good at the symmetric social optimum in the baseline treatment (g_i=13). In the lottery treatment, individuals acting in a self-interested manner will contribute the same amount as they would if a social planner controlled their actions.

In total, 30 young adults participated in this computer-mediated experiment held at the University of New Brunswick in Saint John.[8] Groups of three people were formed. Five groups participated in the baseline (PG9) treatment and five groups participated in the lottery (PG12) treatment. In each case, subjects were read instructions which described how their allocation decision of a fixed number of tokens each period would lead to a payoff depending on how much they allocated to market 1 (a private good) and market 2 (a public good).[9] Subjects were informed that group membership would remain constant for the entire 15 periods of the experiment. With 15 people in the room it was difficult for subjects to ascertain exactly who was in their group. Moreover, subjects were informed that their payoff tables were identical to the other members of their group. In PG9, subjects made voluntary contribution decisions, whereas in PG12, subjects selected the number of tokens they would like to see allocated to the public good, and this was randomly assigned to a member of their group. Payoffs in lab dollars were converted into Canadian dollars at the known rate of 200:1. Sessions lasted approximately 1.5 hours. Average earnings were $23.33. The minimum payoff earned was $17.50 and the maximum was $29.00.

The predictions in this experiment are quite simple. First, if the mechanism is effective, then group contributions should increase under the lottery assignment treatment.

Hypothesis 1 **H_0:** $G_{\mathrm{PG12}}=G_{\mathrm{PG9}}$ vs. **H_A:** $G_{\mathrm{PG12}}>G_{\mathrm{PG9}}$

By extension, the increase in voluntary contributions should increase efficiency.

Hypothesis 2 **H_0:** $EFF_{\mathrm{PG12}}=EFF_{\mathrm{PG9}}$ vs. **H_A:** $EFF_{\mathrm{PG12}}>EFF_{\mathrm{PG9}}$

The final prediction is that in PG12, individual contributions are (or at least converged to) g_i=13, which is the Nash equilibrium prediction of the lottery model. That is, although hypotheses 1 and 2 may be satisfied, it may not be because the lottery mechanism works as predicted.

Hypothesis 3 **H_0:** $g_{i,\mathrm{PG12}}=13$ vs. **H_A:** $g_{i,\mathrm{PG12}}\neq 13$.

IV. Results

Rarely are results so blatantly obvious as they are in this case. There is strong evidence that the lottery model greatly enhances the provision of the public good. The average aggregate contribution of 21.1 in the baseline case increased to 33.3 under the lottery treatment.

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[8] The software was developed at McMaster University and was run on a UNIX platform.

[9] Complete sets of instructions and payoffs are available from the author.

Result 1

Group contributions to the public good were increased under the lottery treatment relative to the baseline treatment.

Support

A glance at Figure 1 shows that aggregate contributions increased in PG12 when compared to PG9. The symbols in the graphs represent the contributions made in each period by each group. The line connects the median aggregate contribution of the 5 groups. The two straight lines represent the Nash prediction (G=15) and the social optimum (G=39).

There exists some convergence in PG9 towards the Nash prediction of 15. In PG12 however, convergence seems to be towards an aggregate contribution of 39. This conclusion is further supported by the results of an exact randomization difference of means test (Moir, 1998) presented in Table 3.[10] Although there is not enough evidence to reject the null hypothesis of no difference in aggregate contributions in periods 1 and 5, there is strong evidence to reject such a null in periods 10, 14, 15 and when group results are averaged over periods 2 through 14 so first round and end-game effects are ignored. In these cases, one-sided tests never have p-values in excess of 0.028. It is evident that the lottery mechanism is effective in increasing the amount of public good provided.

Result 2

The implementation of a lottery mechanism increases efficiency.

Support

This result follows directly from Result 1. However, with an interior solution to this public good problem, it is possible that too much of the public good can be provided. Despite this issue, Figure 2 shows that efficiency in PG12 exceeds efficiency in PG9. Note that under this payoff scheme, achieving the aggregate Nash equilibrium of 15 tokens results in over 72% efficiency (see horizontal line in Figure 2). Because the gains to cooperation depend critically upon the nature of the payoff function, that is they depend upon the type of public good or common-pool resource, it does not make sense to analyze efficiency numerically.[11] However, this conclusion is reinforced in Figure 3, in which the efficiency gain over-and-above that possible if the Nash equilibrium is achieved is presented. In PG12, the median value for the efficiency gain is always above 75%, whereas in PG9 the median efficiency gain never reaches this value.

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[10] In the implementation of this experiment some errors were made which are not likely in the field. One particular subject contributed more than the share s/he received in one period, and less than the share s/he received in another. In two more periods, two of the shares were switched across groups. In these last two cases, average aggregate contribution is not affected, but efficiency is a bit off. The conclusions do not change in either case. These ‘errors’ will be discussed in more detail in the conclusion.

[11] Consider a linear public goods environment, in which the Nash prediction is no contribution. At the Nash solution, efficiency is very low as none of the public good is provided. Similarly, at the social optimum (usually meaning all contributions go towards the public good), efficiency is 100%. The results presented here would have been much more dramatic had a linear public good payoff function been used, but in no way would they have been more meaningful.

Result 3

Although the lottery mechanism increases aggregate contributions to the public good, it does not necessarily do so in the predicted manner. Individual contributions do not necessarily converge to 13.

Support

In order to test this hypothesis, the following regression was run,

$$g_{i,t}=\alpha_1 t+\beta_1\mathrm{D1}+\beta_2\mathrm{D2}+\beta_3\mathrm{D3}+\beta_4\mathrm{D4}+\beta_5\mathrm{D5}+\epsilon_t,$$

where t is the period number, and D1=1 for group 1 and 0 otherwise, and so on.[12] With the time effects removed, the β coefficients represent the average individual contributions for each group. For β_1-β_5 these values are 10.3, 5.9, 9.4, 13.8, and 11.9. All five coefficients are significantly different than zero. Only in the case of β_2 do we fail to reject the null that the mean individual contribution is 5 — on average all groups, other than group two, contained individuals who contributed more than the Nash equilibrium prediction of the purely voluntary model. However, only in the cases of β_4 and β_5 do we fail to reject the null that individual contributions are centered around 13. Thus, only in groups four and five do we see the lottery mechanism working as predicted by theory, at least on average. This suggests that although the lottery mechanism increases contributions (reduces the free-rider problem), individuals do not necessarily follow the behaviour predicted by the model.

V. Conclusions and Discussion

In this research, I have identified an endogenously determined field 'solution' to the commons problem, namely a lottery distribution scheme. Not only did the lottery mechanism have a long history in Hirano Japan, it is shown to be a working solution both theoretically and behaviourally. These are both important steps in understanding what makes the commons 'work'. Just because a mechanism is used in the field does not necessarily mean that it is effective. Neither is it possible to determine why the mechanism works and how it can be modified to work in other situations.

The lottery mechanism was tested in a public good experiment. The data suggest that the lottery mechanism increases contributions to the public good and thus enhances cooperation. However, it does not work exactly as described by economic theory. In fact, it falls short of the 100% efficiency predicted by the model. Is this bad? Not necessarily. Subjects realized significant gains in their monetary rewards. Although the mechanism is not perfect, it is considerably better than no mechanism at all.

Economic experiments have an additional benefit. They can often reveal potential pitfalls before a scheme is widely implemented. In this experiment, four 'errors' were made. Two of them were experimenter errors involving problems with the random distribution of selected shares. This portion of the experiment was conducted by hand. However, it is reasonable to assume that this will not be a problem in the field — in most cases one village will be participating at a time, while we were dealing with five groups simultaneously. Two additional errors were caused by one individual. In

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[12] A simple linear regression was run. It is possible that this data is censored by the non-negativity of contributions constraint and by the maximum endowment of individuals. However, running a tobit regression with the lower bound set to 0 and the upper bound set to 20 has minimal effects upon the coefficient values and does not alter the conclusions of the hypothesis testing.

period 1, this individual contributed 5 additional tokens (10 instead of the 5 s/he was assigned on the slip of paper). In period 4, s/he contributed 1 less token (2 instead of 3). Although these errors create negligible changes to the overall results, they warn that even this mechanism would have to be carefully monitored.

These results are extremely promising, but lead to additional research questions. Are there other factors that exist in the field which would suggest that the lottery mechanism is more effective than that predicted by these laboratory results? What would happen if group membership varied? What if heterogeneity was involved? Would a larger group increase cooperation, or at least would it make individuals act more in line with theoretical predictions? A different line of research is necessary to examine whether people would voluntarily adopt a lottery mechanism. Still, we now have an indication that the lottery mechanism was actually an important component in making winter fodder harvesting a "workable" commons in Hirano, Japan. Armed with this knowledge, we can begin to look for other situations which might benefit from a lottery mechanism. Moreover, we can start to look for other 'field' solutions which can be put to the test, both as a theory and in the lab.

Table 1

Design Parameters

Parameter	Value
n	3
w_i	20
a	4.64
τ	1/9

Table 2

Contribution Predictions

Model	Contribution (g_i)	Payoff (π_i) in \$L	Share (g_i/w_i)
Nash	5	255.20	1/4
Social	13	354.19	13/20

Table 3

Comparison of Group Contribution (G) by Period (PG12 vs. PG9)

	Average Group Contribution		Test[13]	
Period	**PG12**	**PG9**	**t statistic**	**ER (p-value)**
1	26.4 (25.4)	22.4 (22.4)	0.740 (0.558)	0.250 (0.306)
5	35.2	25.8	1.276	0.131
10	34.0 (34.0)	21.2 (21.2)	2.254 (2.600)	0.028 (0.016)
14	34.2	20.0	2.998	0.012
15	38.6	14.0	5.179	0.004
avg. 2-14	33.4 (33.4)	21.6 (21.6)	2.737 (2.770)	0.016 (0.016)

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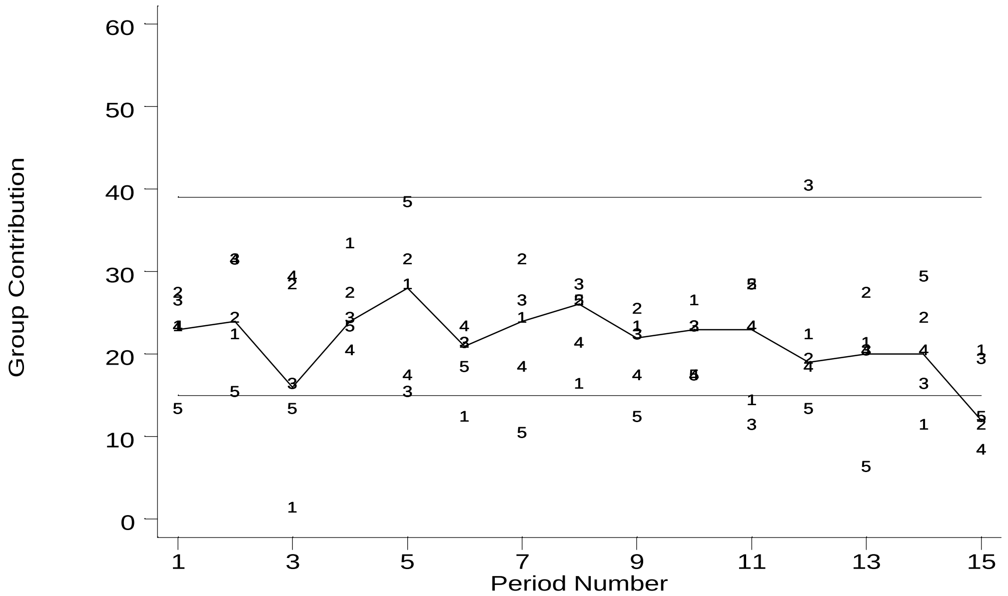
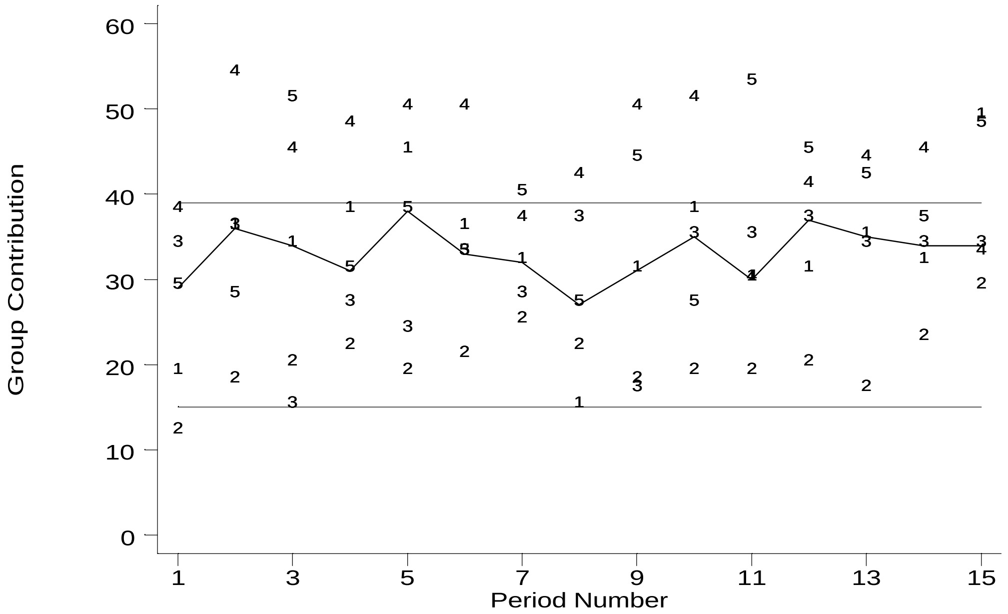
[13] The exact randomization (ER) difference in means test (Moir, 1998) is one-sided. The values in brackets account for cases in which errors were made (when selected shares and actual contributions did not agree). Note that the results do not differ.

Figure 1

Aggregate Contributions to the Public Good
Baseline vs. Lottery Mechanism



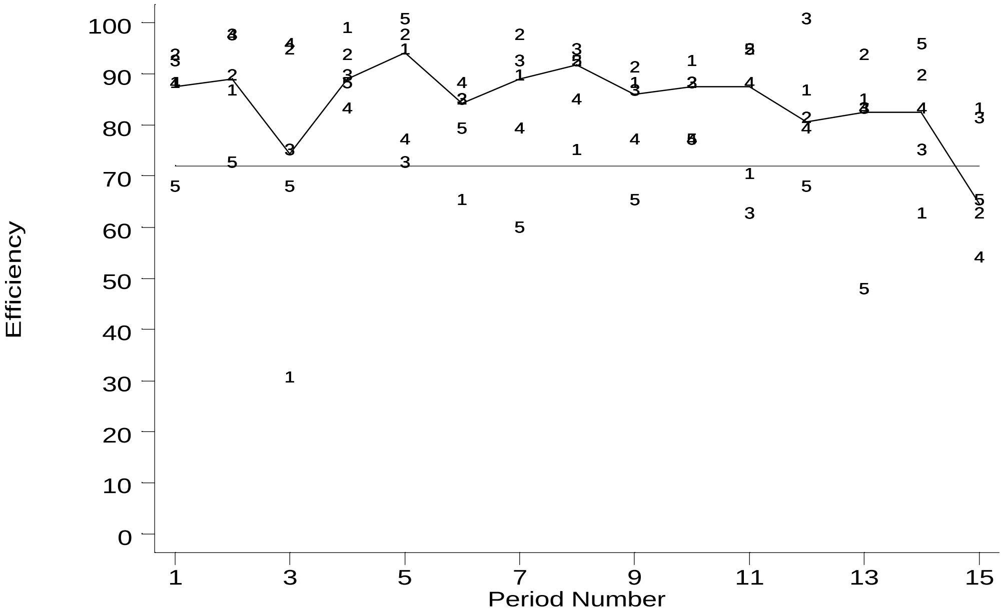
Group Contribution, Baseline



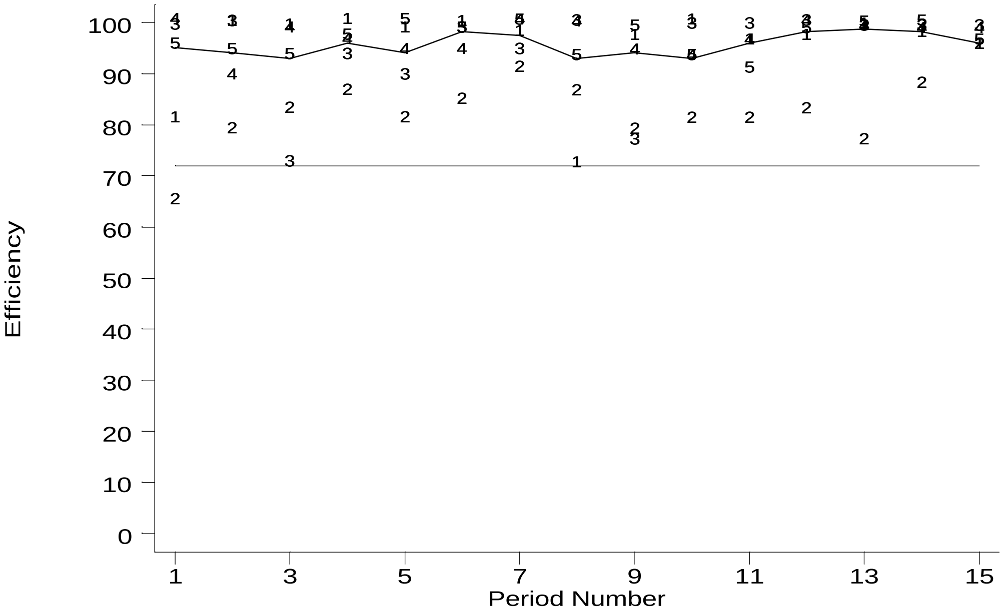
Group Contribution, Lottery

Figure 2

Efficiency
Baseline vs. Lottery Mechanism



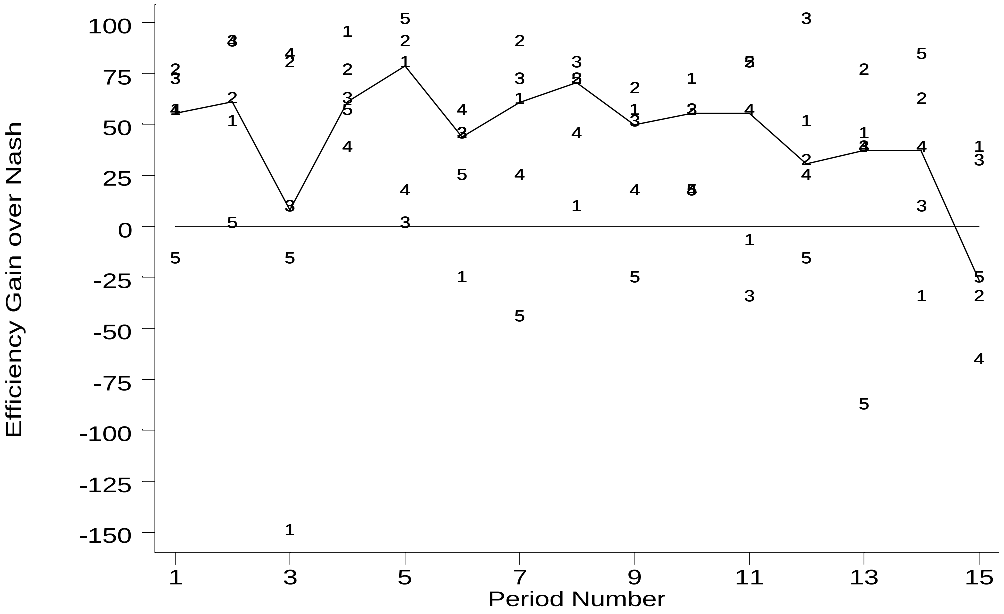
Efficiency, Baseline



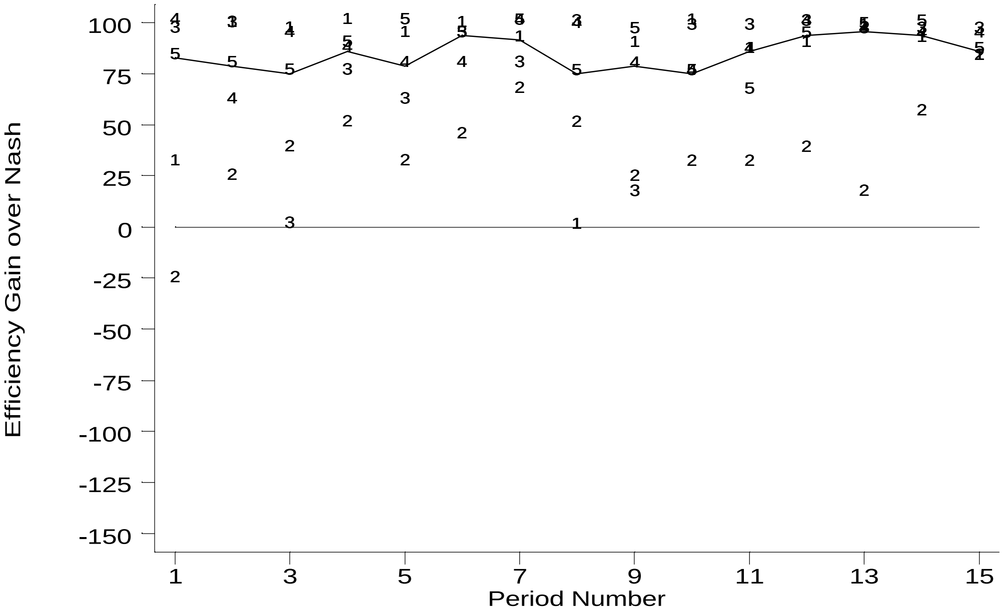
Efficiency, Lottery

Figure 3

Efficiency Gain, over Nash
Baseline vs. Lottery Mechanism



Efficiency Gain over Nash, Baseline



Efficiency Gain over Nash, Lottery

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