A simple mechanism for the efficient provision of public goods - experimental evidence

by

Josef Falkinger*+

Ernst Fehr, Simon Gächter****

Rudolf Winter-Ebmer***

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***** Department of Economics, University of Regensburg, D-93040 Regensburg, Germany; Fax: +49-941-943-4941, e-mail: josef.falkinger@wiwi.uni-regensburg.de.

****** Institute for Empirical Research in Economics, University of Zurich, Blümlisalpstrasse 10, CH-8006 Zurich, Switzerland; Fax: +41-1-63 44907, e-mail: efehr@iew.unizh.ch, gaechter@iew.unizh.ch.

******* Centre for Economic Policy Research, London, and Department of Economics, University of Linz, Altenberger Strasse 69, A-4040 Linz, Austria; Fax: +43-732-2468-238, e-mail: r.winterebmer@jk.uni-linz.ac.at.

\+ Corresponding author.

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Abstract

This paper presents an experimental examination of the Falkinger (1996) mechanism for overcoming the free-rider problem. The basic idea of the mechanism is that deviations from the mean contribution to the public good are taxed and subsidized. The mechanism has attractive properties because (i) it induces higher contributions to the public good and can implement an efficient level of contributions as a Nash equilibrium, (ii) the government budget is always balanced irrespective of the level of individual contributions, (iii) it is simple and policy makers need only little information to implement the mechanism.

To examine the empirical properties of the mechanism we conducted a large series of experiments. It turns out that the introduction of the mechanism generates immediate and large efficiency gains. This result is robust throughout many different experimental settings. Moreover, in the presence of the mechanism the Nash equilibrium is a rather good predictor of behavior.

Keywords: public goods, efficient provision, voluntary contributions, experiments, mechanisms

JEL-Classification No.: H41, C91

1. Introduction

Free riding incentives are a pervasive phenomenon of social life. In case of private provisions of public goods free riding leads to inefficient underprovision. Economic theory explains this by viewing contributions to a public good as strategies in a noncooperative game (Bergstrom, Blume and Varian 1986, Cornes and Sandler 1986). Experimental evidence suggests that subjects are sometimes more cooperative than predicted by economic theory (Davis and Holt 1993, Dawes and Thaler 1988, Ledyard 1995). Yet, the same evidence shows that underprovision of the public good relative to the efficient level of contributions is also pervasive. This holds true for one-shot interactions as well as in case of repeated interactions. The tendency to underprovide is particularly strong towards the end of a finite number of repetitions of a voluntary contribution game (Isaac, Walker and Thomas 1984, Ledyard 1995).

Economic theorists have reacted to the free riding problem by designing sophisticated mechanisms for the implementation of an efficient allocation of public goods (e.g. Clarke 1971, Groves 1973, Groves and Ledyard 1977, Green and Laffont 1979, for a survey see Laffont 1987). This literature has greatly increased our knowledge about the incentive compatibility requirements for the Pareto optimal provision of public goods. However, as has been pointed out by the proponents of this literature, the proposed mechanisms are frequently rather complicated and, hence, difficult to implement. In his survey on "Incentives and the Allocation of Public Goods" Laffont (1987, p. 567) writes for example: "... any real application will be made with methods which are crude approximations to the mechanisms obtained here ... considerations such as simplicity and stability to encourage trust, goodwill and cooperation, will have to be taken into account."

Recently, several authors have proposed incentive mechanisms which induce efficient contributions to the public good and seem to meet the requirements of simplicity. Varian (1994a), for example, examined a simple two-stage game in which agents have the opportunity to subsidize the other agents' contributions. This mechanism relies on the concept of subgame perfection.[1] Earlier, Bagnoli and Lipman (1989) have presented an attractively simple sequential voluntary contribution game that implements the core of the economy. However, the implementation requires a rather complex and particular refinement of the Nash-equilibrium.[2] Other recent proposals deal with mechanisms in which the government

1 Varian (1994b) generalizes the mechanism to other economic environments involving externalities. Guttman (1978, 1987) and Danzinger and Schnytzer (1991) consider a similar game in which individuals choose subsidy rates in the first stage and decide in the second stage about their contributions to the public good, given the subsidy rates chosen in the first stage. A critical assessment of their analysis is provided by Althammer and Buchholz (1993).

2 Bagnoli and McKee (1991) and Bagnoli, Ben-David and McKee (1992) tested this mechanism experimentally.

tries to increase contributions to the public good by suitable tax-subsidy schemes. Such mechanisms are not purely private since they require a central authority which can enforce taxes. The relevant question is whether a government with no information about private characteristics can design a tax-subsidy scheme which induces people to contribute more to the public good. The literature on the neutrality of lump-sum payments (Warr 1982, 1983) or income taxation (Bernheim 1986) shows that this is not a trivial task.[3] Andreoni and Bergstrom (1996) put forward an interesting model of tax-financed government subsidies to private contributions which definitely increase the equilibrium supply of public goods.[4] Falkinger (1994) has shown that the private provision of public goods increases significantly if people value the relative size of their contributions positively. In Falkinger (1996) a simple tax-subsidy scheme is designed which induces people to take into account the relative size of their contributions in such a way that an increased or even an efficient level of public good provision is achieved as a Nash equilibrium.[5] This tax-subsidy scheme works as follows: For each given income class, deviations from the average contribution of this income class are rewarded or penalized. More specifically, if an individual's contribution is b_i units above the mean contribution of the other members of her income class she gets paid βb_i. She gets thus a subsidy of β for a marginal increase in her contribution. In contrast, if her contribution is b_i units below the average of other members she has to pay a tax of βb_i. Thus, a marginal increase in her contribution reduces her tax payment by β. It can be shown that, in equilibrium, this strikingly simple incentive scheme produces an efficient amount of the public good if β is chosen appropriately. In addition, the mechanism is fully self-financing, irrespective of whether subjects are in or out of equilibrium.

All of the above mentioned mechanisms are desirably simple and do well in theory. It is, however, important to note that the fact that a mechanism does well in theory, does not tell us much about its effectiveness in the laboratory or in practice. In principle, it could well be the case that although the Nash equilibrium in the presence of the mechanism implies an efficient provision of the public good, subjects' actual behavior will generate significant under- or overprovision. Since the pioneering experimental work of Smith (1979a, 1979b, 1980) and Harstad and Marrese (1981, 1982) it is clear that laboratory tests are in order to provide reliable evidence on whether the empirical properties of a proposed mechanism deviate from the theoretical predictions. For example, in a recent paper by Chen and Plott (1996) it turns

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3 See Brunner and Falkinger (1995) for a general characterization of neutral and nonneutral taxes and subsidies in an economy with private provision of public goods. Andreoni (1993) tested the neutrality of lump-sum taxes experimentally and found that neutralization is incomplete.

4 Boadway, Pestieau and Wildasin (1989) and Roberts (1992) have also considered games in which the state subsidizes the individual contributions to the public good so that an efficient allocation is realized in the Nash equilibrium. Their analysis rests on the assumption that individuals do not anticipate the taxes by which the subsidies are financed.

5 For an application of the mechanism to the reduction of global CO_2-emissions see Falkinger, Hackl and Pruckner (1996).

out that the performance of the Groves-Ledyard mechanism critically depends on the size of a so-called punishment parameter. Theory says that if this parameter is positive a Pareto efficient solution can be implemented as a Nash equilibrium. Therefore, according to the theory the *size* of this parameter should not affect the performance of the mechanism. In fact, however, the size of the punishment parameter is crucial. A further example for the importance of laboratory tests is provided by Bagnoli, Ben-David and McKee (1992). They show that Bagnoli and Lipman's mechanism "does not appear ... to generate core allocations or even something close" in case of multiple units of the public good (Bagnoli, Ben-David, McKee 1992, p. 97).

Deviations of actual behavior from the equilibrium predicted by theory can be due to coordination problems or to bounded rationality of actual subjects. They also can arise because subjects' motivations differ from the theoretically assumed preferences. That deviations from equilibrium are potentially relevant is also indicated by the stylized facts of finitely repeated voluntary contribution games.[6] In these experiments there seem to be many factors at work which are not well understood and about which standard theory is silent. One factor which has recently received increasing attention is the possibility that subjects are "confused", i.e. that individual choices reflect some fundamental randomness (see Andreoni 1995, Palfrey and Prisbrey 1993, Plott 1996). Can we be sure that factors like, for example, "confusion" do not impede adjustment towards the efficient outcome in the presence of an incentive mechanism?

In this paper we report the results of a large series of experiments which have been designed as a test of the practical tractability and effectiveness of the incentive mechanism proposed by Falkinger (1996). We implemented treatments with and without the mechanism. In our control treatment there was no mechanism so that subjects faced strong free-riding incentives. In the so-called mechanism treatment we implemented the Falkinger mechanism. Everything else was the same in both treatments. Therefore, we can examine the impact of the mechanism by comparing contribution behavior under the two treatments. To allow for learning the basic stage game in both the control treatment and the mechanism treatment was repeated several times.

We studied the impact of the mechanism in different economic environments. In particular, we varied group size and players' payoff functions so that the Nash equilibria differed systematically across environments. In some environments the Nash equilibrium was at the boundary of the subjects' strategy space while in others it was in the interior. Also, in some

[6] In these games the Nash-prediction frequently involves zero contributions. Nonetheless, there is initially a relatively high rate of contributions. Towards the end, the Nash equilibrium is approached for reasons which are not well understood. For a recent attempt to explain this evidence see Fehr and Schmidt (1997).

environments all individuals had identical preferences while in others they were different. The results of our experiments indicate that the proposed incentive mechanism is very promising. In each of the implemented economic environments the mechanism caused an *immediate* and *large* shift towards an efficient level of provision of the public good. This suggests that little practical experience with the mechanism is necessary to induce a large increase in contributions. This property of the mechanism is probably due to its simplicity.

A further remarkable fact is that the Nash equilibrium is a rather good predictor of behavior under the mechanism. If the Nash equilibrium lies at the boundary of subjects' strategy space a vast majority of individuals plays exactly the equilibrium strategy. If the Nash equilibrium is in the interior of subjects' strategy space, contributions are relatively close to the equilibrium. In contrast, in the control treatments there was, in general, considerable overcontribution relative to the equilibrium in the early periods. Towards the end, however, behavior was very close to the Nash prediction in the control treatments, too.

The remainder of this paper is organized as follows: Section 2 introduces the mechanism to be examined. Section 3 discusses the experimental design, and in Section 4 the empirical results are presented. Section 5 interprets these results and provides a summary.

2. The mechanism

Consider an economy of n individuals with incomes y_i, $i = 1, ..., n$. They have preferences over private consumption c_i and a public good G represented by a strictly quasi-concave and differentiable utility function

$$u^i(c_i, G). \tag{1}$$

The public good is provided by voluntary contributions that is,

$$G = \sum_{i=1}^{n} g_i = g_i + G_{-i}\,, \tag{2}$$

where g_i denotes the contribution of individual i and $G_{-i} := \sum_{j \neq i} g_j$. It is assumed that the price of c_i equals one. p_G is the price of the public good. Thus, without taxes and subsidies the individual budget constraint is given by

$$c_i + p_G g_i = y_i\,, \quad i = 1,..., n. \tag{3}$$

The standard approach to the private provision of public goods is based on Nash behavior. The members of the economy choose their contribution g_i under the assumption that the contributions of the others are given. In case of an interior solution maximization of (1) subject to (2) and (3) gives us for a fixed G_{-i}

$$MRS^i = p_G, \quad i = 1,..., n \tag{4}$$

with $MRS^i \equiv (\partial u^i/\partial G)/(\partial u^i/\partial c_i)$. Under the assumption that both the private and the public good are normal goods for all individuals, equations (3) and (4) describe a unique Nash equilibrium $c_1, ..., c_n$ and $g_1, ..., g_n$ (see Bergstrom, Blume and Varian 1986). In contrast to (4), the efficient provision of the public good requires that the rule (Samuelson 1954)

$$\sum_{i=1}^{n} MRS^i = p_G \tag{5}$$

is fulfilled. By comparing (4) and (5) one obtains the known fact that public goods are underprovided in a private equilibrium.

The problem of the underprovision of public goods can be overcome by the following simple incentive scheme (Falkinger 1996): Each individual gets a reward or has to pay a penalty depending on the deviation of its contribution from the mean contribution, where the mean to which an individual's contribution is compared may be the average contribution of the whole population or the average contribution of the income class to which the individual belongs. A differentiation according to income is not important if clubs with more or less equal income earners are considered or small-sized public projects are to be provided, for which the share of the contribution to the public good in the household budget is small even for a poor contributor. However, if more substantial public programs should be supplied, the differentiation is essential. Suppose, for instance, that average income earners contribute one third of their income to the public good and that a poor individual earns only one fourth of the mean income. Then the poor would have to pay a penalty even if he contributed all his income to the public good. This problem is avoided by matching each individual only with other members of the same income class. Notice that the partitioning of individuals into income classes does not imply that people who are in the same income class have identical preferences. The mechanism allows heterogeneous preferences within and across income classes.

Formally, let $k = 1,.....,m$ be the income classes in the economy and let I_k be the set of individuals in class k. The government imposes that an individual i belonging to income class k gets a subsidy (or has to pay a tax) r_i according to the rule

$$r_i = \beta p_G \left(g_i - \frac{1}{n_k - 1} G_{-i}^k \right) \qquad (6)$$

where $n_k \leq n$ is the number of people belonging to the income class k , and $G_{-i}^k \equiv \sum_{j \in I_k - \{i\}} g_j$ is the sum of all contributions of members of this income class minus the contribution of individual i. β is a constant subsidy rate.

For the government this rule has the advantage that the budget is balanced whatever the price of the public good and whatever the contributors decide to do. ($\sum_{i=1}^{n} r_i = 0$, since by definition for each income class, $\sum_{i \in I_k} G_{-i}^k = (n_k - 1) \sum_{i \in I_k} g_i$). For individual i belonging to income class k the budget constraint becomes:

$$c_i + p_G g_i = y_i + \beta p_G \left(g_i - \frac{1}{n_k - 1} G_{-i}^k \right) \qquad i = 1, ..., n. \qquad (7)$$

Maximization of (1) subject to (2) and (7) yields for given values g_j, $j \neq i$:

$$MRS^i = (1 - \beta) p_G, \qquad i = 1, ..., n. \qquad (8)$$

Thus, reward scheme (6) implies that the price of the public good is subsidized from p_G to $(1 - \beta)p_G$. As a consequence, the contributions g_i to the public good will increase for $\beta > 0$ compared to a situation with no mechanism $(\beta=0)$. Moreover, if $\beta = 1 - (1/n)$, the first-order-conditions in (8) imply that the Samuelson rule $\sum_{i=1}^{n} MRS^i = p_G$ for an efficient level of provision of the public good is fulfilled. It is shown in Falkinger (1996) that (7) and (8) define an efficient equilibrium for $\beta = 1 - (1/n)$. This means that an efficient level of contributions to public goods can be achieved as a Nash equilibrium by using the incentive scheme defined in (6). The intuition behind this result is as follows: The private benefit of an additional unit contributed to the public good is MRS^i, which is on average $1/n$ of the social benefit $\sum_{i=1}^{n} MRS^i$. This leads to underprovision if people are confronted with the full cost of contribution, p_G. The mechanism with $\beta = 1 - 1/n$ reduces the marginal cost of contributing to the public good to $(1 - \beta)p_G = p_G/n$. This matches the $1/n$ share of the social benefit and, hence, an efficient level of contributions is achieved. The budget balance problem is solved by using the fact that deviations from average sum to zero.

While the above scheme rewards and penalizes *deviations* from the average contribution, others proposed to pay subsidies bound to the *level* of contribution. Boadway, Pestieau and Wildasin (1989) and Roberts (1987, 1992) discuss a system of matching grants in a model in which contributors do not take into account that the grants have to be financed by taxes. Andreoni and Bergstrom (1996) showed that contributions to public goods can be increased by subsidies to the level of contributions if the contributors have no budget illusion. With our incentive scheme (6) the contributors are also free from budget illusion. If they fully account for the impact of their action on the government budget, they see that it is always balanced. There is an important additional advantage of scheme (6). By subsidizing deviations from the average contribution instead of the level of contribution, the size of the required public budget transactions is substantially reduced. Consider for instance the case of identical contributions by all individuals. Then actually no subsidy and tax payments are paid, and contributions to the public good are increased without involving any public budget transactions.

Does the proposed scheme, which works in theory, and which has rather attractive properties from an economic policy point of view, also work in practice? The experiments described in the next section put the theoretical proposal to the test.

3. Experimental Design

To investigate the empirical properties of the mechanism we implemented two basic treatments - a control treatment and a mechanism treatment.[7] In the control treatment the tax-subsidy parameter β was always zero, i.e., there was no mechanism, while in the mechanism treatment $\beta > 0$ was chosen. Within these basic treatments we varied the economic environment in a systematic manner. We varied, in particular, the group size n, the payoff function, i. e., the marginal rate of substitution between c_i and G (MRS^i), and the tax-subsidy parameter β. Across all treatment conditions and economic environments the price of G, p_G, was set equal to one. The characteristics of the different experimental designs are summarized in Table 1. We discuss first the treatments C1-M3 in which the equilibria were at the boundary of the individuals' strategy space. After that we turn to treatments C4-M5 which implemented interior equilibria.

In the control treatments C1-C3 and the mechanism treatments M1-M3 each player i was endowed with $y = 20$ tokens and the monetary payoff from investing g_i tokens into the public good was given by

7 The instructions are available on request.

$$u^i = c_i + aG$$
$$= y - g_i + \beta[g_i - G_{-i}/(n-1)] + a(g_i + G_{-i}), \quad (9)$$

where $a > 0$ is a given constant. The second line of (9) results after substituting (2) and (7) for c_i and G, respectively.[8]

Table 1: Summary of experimental design and parameters

Treatment	number of groups	group size (n)	marginal rate of substitution between c_i and G (MRS^i)	tax/subsidy parameter (β)	endowment (y)	equilibrium prediction
C1	11	4	0.4	0.0	20	$g_i = 0, \forall i$
M1	18	4	0.4	0.7	20	$g_i = 20, \forall i$
C2	9	8	0.2	0.0	20	$g_i = 0, \forall i$
M2	9	8	0.2	0.9	20	$g_i = 20, \forall i$
C3	2	16	0.1	0.0	20	$g_i = 0, \forall i$
M3	2	16	0.1	1.0	20	$g_i = 20, \forall i$
C4	18	4	$[1/(5-0.1c_i)]$	0.0	50	$g_i = 10, \forall i$
M4	18	4	$[1/(5-0.1c_i)]$	2/3	50	$g_i = 30, \forall i$
C5	5	4	$[1/(A_i -0.1c_i)]$	0.0	50	$g_L=11; g_H=9$
M5	5	4	$[1/(A_i -0.1c_i)]$	2/3	50	$g_L=39; g_H=21$

Note: In C5 and M5 g_H (g_L) denotes the equilibrium contributions of subjects with a „high“ („low“) valuation of the *private* good. Subjects with a high (low) valuation of the private good have $A_i = 5.1$ ($A_i = 4.9$).

Both in C1 and M1 the group size was $n = 4$ and MRS^i was given by $a = 0.4$. However, while $\beta = 0$ in C1, β is set equal to 0.7 in M1. According to (9) the total marginal return of g_i is a constant. It is equal to $-1 + a = -0.6$ in the control treatment C1 so that complete defection is a dominant strategy. In contrast, in M1 the total marginal return of g_i is given by $-1 + \beta + a = +0.1$. As a consequence $g_i = y = 20$ is a dominant strategy for every player. Since $\sum_{i=1}^{n} MRS^i = na = 1.6 > p_G = 1$, efficiency requires that the whole endowment is invested into the public good. Thus, while the mechanism treatment implements an efficient solution the control treatment implements an equilibrium with full defection. The advantage of

8 Note that we have assumed only one income class.

implementing linear preferences and a corner solution is that the results of the control treatment C1 are easily comparable with the stylized facts of many similar experiments. This provides us with information about whether there are any peculiarities in our data.

During the experiment each of the n subjects simultaneously chose a contribution g_i. To allow for learning this constituent game was replicated ten times. By backward induction, to contribute nothing (everything) to the public good is still a strictly dominant strategy in the control treatment C1 (mechanism treatment M1). At the end of each period subjects were informed about the average contribution of the other group members, their own income from c_i as well as their income from the public good aG. Group members did not know with whom they formed the group and they were informed that they will never learn it. The ten-fold replication makes our control experiment comparable to similar experiments described in the literature (see Davis and Holt 1993 or Ledyard 1995). In addition, the replication enables us to study the evolution of behavior over time. From many public goods or market experiments it is known that subjects seldomly jump directly into the equilibrium. Instead, they converge more or less quickly to the equilibrium.

In total 11 groups participated in C1-sessions and 18 groups in M1-sessions. Six groups participated in both C1 and M1. These groups participated first in a C1-session upon which they played an M1-session. As we will discuss in the next section, a typical result of linear public good experiments with $\beta = 0$ is that in the first periods subjects contribute 40 to 70 percent of their tokens to the group account and that the level of contributions drops to 5 to 20 percent in the last periods. This means that subjects experience a lot of free-riding during these experiments. From a psychological point of view the experience of free-riding may influence behavior in the mechanism treatment. Moreover, there is some experimental evidence that experienced subjects contribute less to the public good (Isaac, Walker and Thomas, 1984, 1991). The sequence of C1-M1 sessions provides, therefore, a robustness test for the mechanism. By comparing the behavior of those M1-groups who first played in a C1 session with the behavior of the other M1-groups who did not play in a C1 session we can study the impact of free-riding experience on the functioning of the mechanism.

In the treatments C2 and M2 also payoff function (9) was implemented. In contrast to C1 and M1, however, we increased the group size to $n = 8$. This change allows us to investigate to what extent the functioning of the mechanism depends on group size. To make the experiments with different group sizes comparable we made the following adaptions: We adjusted the MRS to $a = 0.2$ in order to keep $\sum_{i=1}^{n} MRS^i = na$ equal to the C1 and M1 treatment. If we had instead kept the MRS constant at $a = 0.4$ while increasing the group size to $n = 8$ we would have doubled the aggregate gains from cooperation ($\sum_{i=1}^{n} MRS^i$) relative to the C1 and

M1 treatment. To render full contributions in M2 a dominant strategy equilibrium we also adjusted β to $\beta = 0.9$. Note that with $a = 0.2$ and $\beta = 0.9$ the return from a marginal contribution in M2 is given by $-1 + 0.2 + 0.9 = +0.1$ which is identical to the marginal return in the M1-treatment. Subjects in M2, therefore, face exactly the same incentives as subjects in M1 although the group size differs. To investigate the issue of group size effects further we increased n to $n = 16$ in C3 and M3. To keep the aggregate gains from cooperation and the marginal return of g_i equal to M1 and M2 we adjusted a to $a = 0.1$ and β to $\beta = 1$.

In the previous treatments the equilibrium was at the boundary of subjects' strategy space. In the control treatments full defection was the unique equilibrium while in the mechanism treatments full contribution for every player was the unique equilibrium. In addition, the aggregate gains were always maximized at the full contribution level. In more complex environments the equilibrium is likely to be in the interior of the strategy space. To test the effects of the mechanism in such environments we conducted a series of experimental sessions in which individuals faced a nonlinear payoff function. The features of these experiments are summarized as treatments C4-M5 in Table 1. In all these treatments group size was $n = 4$. Each subject was endowed with y = 50 tokens and the payoff functions were given by:[9]

$$u^i = A_i c_i - (1/2) B_i c_i^2 + G, \tag{10}$$

where $A_i > 0$ and $B_i > 0$ are constants.

In the C4- and M4-treatments subjects were homogeneous: Each subject's payoff function had the parameters $A_i = 5$ and $B_i = 0.1$. The equilibrium strategy in C4 (with $\beta = 0$) is $g_i = 10$ for all group members. In M4 we implemented $\beta = 2/3$ so that the equilibrium is $g_i = 30$ for all players. Remember that in case of an interior equilibrium the mechanism achieves an efficient solution if β equals $\beta = 1 - (1/n)$ which reduces for $n = 4$ to $\beta = 3/4$.[10] By choosing $\beta = 2/3$ we deliberately implemented an inefficient equilibrium in M4 because from many linear public good experiments it is well known that, on average, subjects tend to overcontribute relative to the equilibrium (Ledyard 1995). We conjectured that the gap between the efficient solution and the equilibrium solution in our nonlinear environment with $\beta = 2/3$ might also generate overcontributions relative to the equilibrium. From a game-theoretic viewpoint we thus exposed the mechanism to a particularly tough test. Since an efficient solution is a potentially strong behavioral attractor the equilibrium predictions are more likely to be violated in this environment.

9 A similar design was used by Keser (1996) and Sefton and Steinberg (1996).

10 With $\beta = 3/4$ the equilibrium is $g_i = 40$ for all players.

In C5 and M5 subjects were no longer homogeneous. They valued private consumption differently. In each group two subjects had a relatively low valuation of the private good, i. e., $A_i = A_L = 4.9$, while the other two subjects had a relatively high valuation of c_i with $A_i = A_H = 5.1$. For all group members B_i was again set equal to $B_i = 0.1$. As before β was set to $\beta = 2/3$ in the mechanism treatment. In the control treatment C5 the equilibrium strategy of subjects with A_L is $g_L = 11$ whereas for subjects with A_H the equilibrium is $g_H = 9$. In the mechanism treatment M5 equilibrium implies $g_L = 39$ for subjects with $A_L = 4.9$ and $g_H = 21$ for subjects with $A_H = 5.1$. Thus, the average equilibrium contribution in the treatments with heterogeneous subjects (C5, M5) is equal to 10 (for C5) and 30 (for M5). It is, therefore, identical to the equilibrium contribution in the treatments with homogeneous subjects (C4, M4). This gives us the opportunity to study the impact of heterogeneity by comparing the average contributions across treatments.

4. Results

In total 240 subjects, who formed 45 independent groups, participated in our control sessions. In the mechanism sessions we had 268 subjects in 52 independent groups.[11] An experimental session lasted between 1.5 and 2 hours. Subjects received a fixed fee of CHF 15 (about $11) for showing up on time plus their earnings in the experiment. The average subject earned about CHF 36 in an experimental session. These earnings surely covered the opportunity costs of participating in the experiments. After reading the instructions, subjects had to solve some hypothetical examples designed to ensure that they are capable to compute their earnings. We did not start the experiment before all subjects had correctly solved all examples.

In reporting our results we proceed as follows. We first document and compare the behavior in the C1 and M1 treatment. Then we study the impact of group size on the mechanism and, finally, we investigate the empirical properties of the mechanism in the environment with interior equilibria.

4.1 The mechanism in a linear environment (corner equilibria)

In the C1 and the M1 treatment we implemented payoff function (9) and a group size of $n = 4$. Figure 1a provides an illustration of the behavior in these treatments. It shows the average contribution to the public good in all C1-groups and the twelve M1-groups which were not exposed to C1. A common characteristic of these groups is that they did not have

[11] The students were from different fields, most frequently from the sciences. Economists were excluded.

prior experience with another treatment. In addition to the average contribution, Figure 1a also shows the 95 percent confidence bounds for the group averages.[12] It is worthwhile to mention that all confidence bounds have been computed with nonparametric methods, i. e., we did not make assumptions about the nature of the underlying distribution.[13]

Basically, the control treatment replicates the results of similar voluntary contribution experiments reported in the literature (see Dawes and Thaler 1988, Davis and Holt 1993 or Ledyard 1995). Voluntary contributions are initially relatively far above the Nash-equilibrium prediction of zero contributions to the public good. However, as it is typical for this kind of public goods experiments, contributions sharply declined towards the end. In the last three periods contributions dropped to an average level of 6.7 tokens. In the last period, contributions decreased to 3.4 tokens on average. A division of the ten periods of C1 into the first half (periods 1 - 5) and the second half (periods 6 - 10) reveals that *all* eleven groups contributed less to the public good in the second half of the experiment (Wilcoxon signed ranks test, p = 0.0017, one tailed). In the last period 57 percent of the subjects contributed zero. This indicates that, finally, the Nash equilibrium had substantial drawing power.

Figure 1a also provides a first indication to what extent the mechanism reduces free-riding. It shows that the incentive scheme indeed substantially increased contribution levels relative to the C1 treatment. In all periods, mean contributions in M1 are above the contributions in C1. Moreover – and contrary to C1 – contributions are increasing and approach the Nash-equilibrium of full contribution. A division of the ten periods of the Mechanism experiment into the first half (periods 1 - 5) and the second half (periods 6 - 10), with group averages as observations, shows that contributions to the public good were significantly higher in the second half of the experiment (Wilcoxon signed ranks test, p = 0.0014, one tailed). „Experienced“ subjects reduce their contributions in the Control treatment but increase them under the Mechanism.

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12 Note that due to a common history the individual contributions within a given group are - except in period one - not independent from each other. However, the average contributions of groups are independent and, therefore, they represent the proper unit of observation for statistical testing and the computation of confidence bounds.

13 To calculate confidence bounds we used the method of bootstrapping. This method is appropriate if one has a random sample from an unknown distribution (see Efron and Tibshirani 1993). The bootstrap only uses the sample information to calculate the standard error of the mean. In our data we used bootstrap samples of N = 1000 drawn randomly (with replacement) from the independent observations (i. e., group averages) of a given treatment. We have calculated the confidence bounds by using the 95 percent trimmed range of the bootstrap sample means.

Figure 1a: The effectiveness of the mechanism - mean contributions (an confidence bounds) in mechanism(M1) and control (C1) treatment

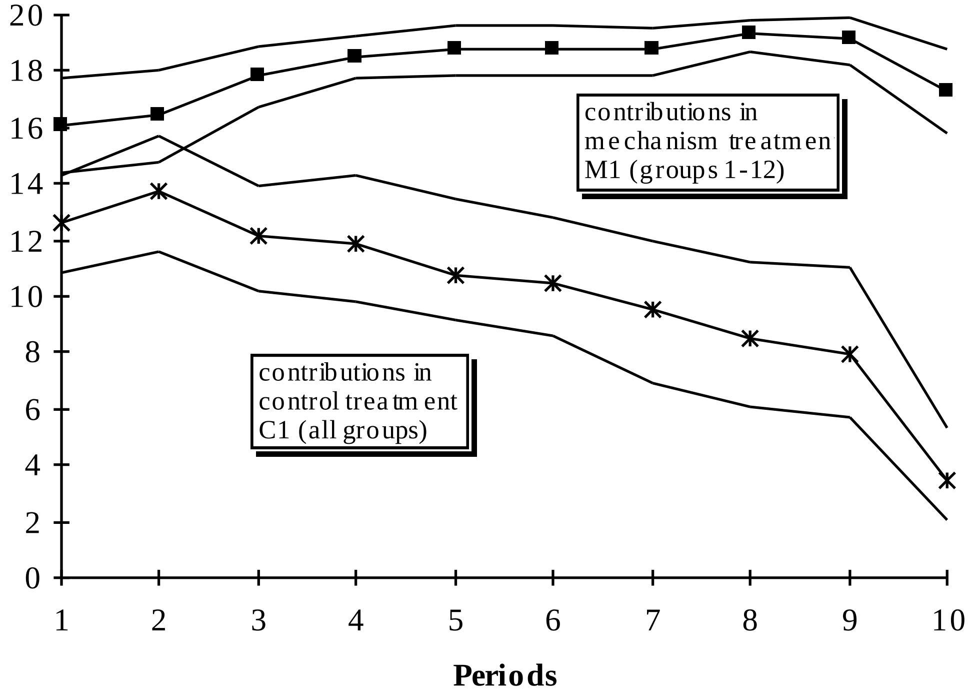

Figure 1b: The robustness of the mechanism - mean contributions (an confidence bounds) of groups 13-18 of M1 after the experience of C

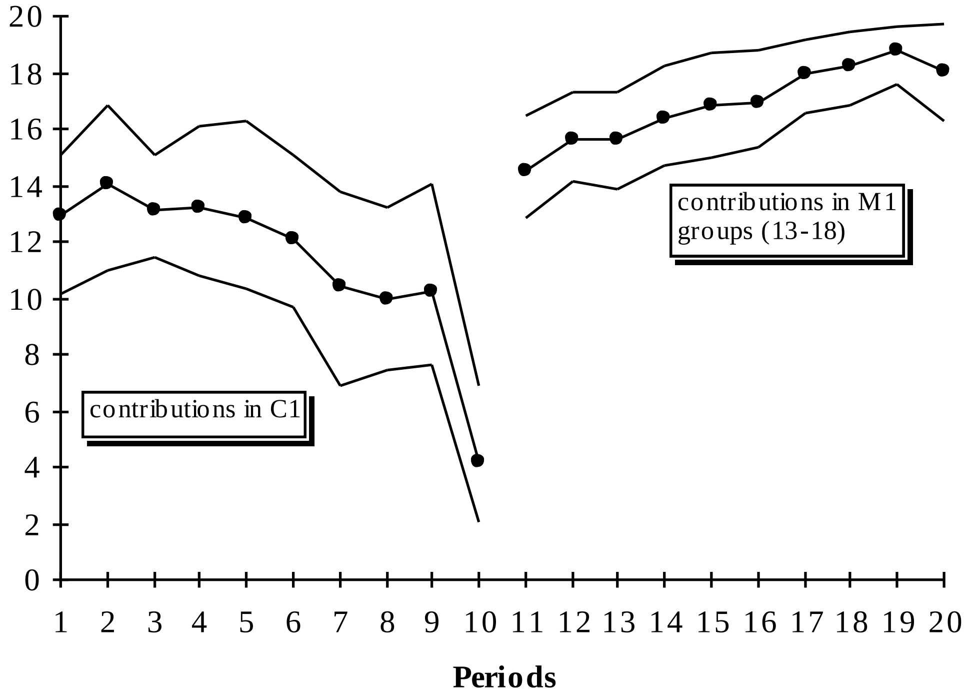

Table 2 contains further information about the behavior under the mechanism. It reports some descriptive statistics for each of the 18 independent groups participating in M1. The mean contribution in groups 1-12 of M1 was very close to the Nash equilibrium. On average, subjects contributed 90.5 percent of their endowment (as compared to 50.5 percent in C1). In the last three periods the average contribution was 18.6 tokens (i.e., 93 percent of the equilibrium) and the median contribution of all subjects of groups 1-12, as well as in 10 out of the 12 individual groups, equaled the equilibrium contribution of 20 tokens. Also in the last period (not shown in the table) the median contribution of all subjects was 20 tokens. This shows that equilibrium contributions are the prevalent behavior in the Mechanism treatment in most of the groups. The mechanism is, however, not only capable of inducing high provision levels that are at or close to the full contribution equilibrium. It also substantially reduces the variability of behavior relative to C1. This becomes apparent from a comparison of the confidence bounds in Figure 1a.

Formal tests of the difference between the C1- and the M1-treatments confirm the picture. Using the independent group averages over all periods as observations, we can reject the null hypothesis that group averages in both treatments are equal in favor of the alternative hypothesis that mean contributions are higher in the Mechanism treatment (Median test, $p < 0.001$, one-tailed).[14]

An interesting test of the power of the mechanism is the first period. Higher contributions in M1 compared to C1 would indicate that not much learning is necessary for the mechanism to be effective, even with completely inexperienced subjects. The null hypothesis that people start contributing to the public good at the same level as in the control treatment has to be rejected (Median test, $p = 0.0178$).[15] In other words, the difference in the average contributions in period 1 across treatments exhibited by Figure 1a is significant. Taken together, the evidence shows that with the mechanism one can achieve significantly higher contribution levels at less variability than with voluntary contributions alone – even without repetition and learning possibilities.

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14 The Median test is a distribution-free test which tests whether two independent samples are drawn from a population with the same median. It is a particularly robust test since it only tests for central tendencies and makes no further distributional assumptions. For our data this test is appropriate since (i) the observations in the two treatments are clearly differently distributed (Kolmogorov-Smirnov-test, $p = 0.033$) and (ii) cluster at the corner of the strategy space. See Siegel and Castellan (1988), p. 124 - 128, for a discussion. The Median test also confirms that group standard deviations are lower in the Mechanism treatment than in the Control treatment ($p < 0.0001$, one-tailed).

15 For this test we used individual decisions in C1 and groups 1-12 of M1 as observations ($N=44$ in C1, and $N=48$ in M1) since in the first period they are all independent.

Table 2: Summary of group behavior (= token contributions to the public good) in the Mechanism treatment M1

Group	mean period 1 - 10	mean period 8 - 10	median period 8 - 10
1	18.2	19.2	20
2	19.1	20	20
3	17.1	20	20
4	16.4	17.3	20
5	16.0	16.5	18
6	18.4	17.8	20
7	19.0	17.5	20
8	19.6	20	20
9	19.4	20	20
10	19.2	18.3	20
11	15.9	16.4	19.5
12	19.1	20	20
total for groups 1-12	18.1 = 90.5 percent	18.6 = 93 percent	20 = 100 percent
13	18.8	19.8	20
14	18.3	19.9	20
15	14.5	15.7	17.5
16	17.8	19.8	20
17	17.1	17.9	17.5
18	15	17	18.5
total for groups 13-18	16.9 = 84.5 percent	18.3 = 91.5 percent	20 = 100 percent

Note: Groups 1 - 12 did not experience a C1 treatment prior to M1. Groups 13-18 played an M1 treatment after a C1 treatment. Percentage rates are calculated with respect to the equilibrium of 20 tokens.

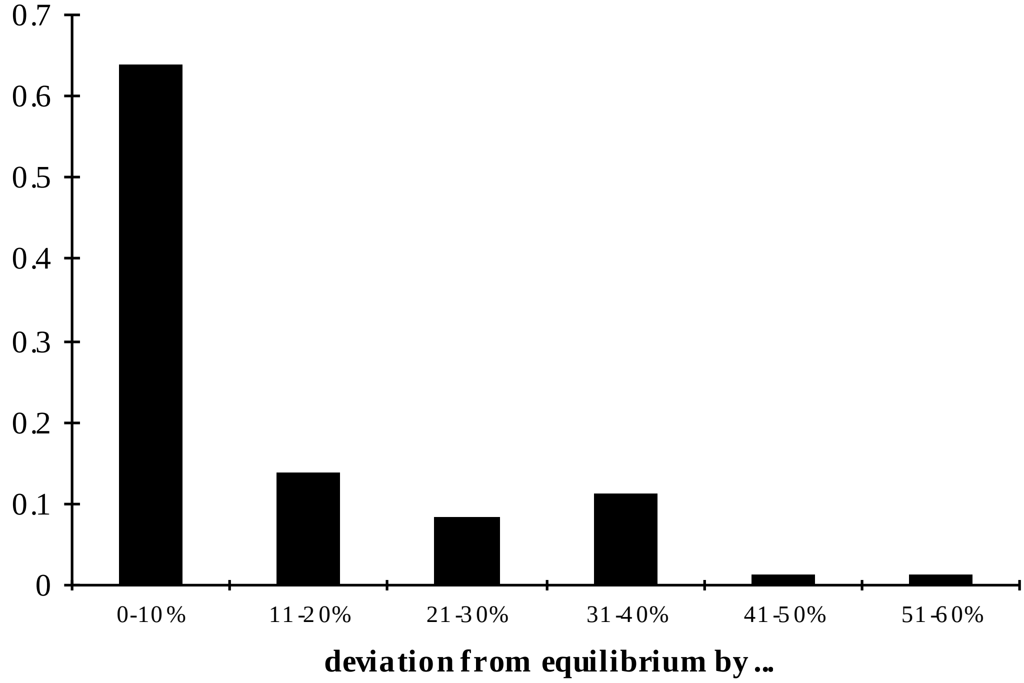
How effective is the mechanism if people already have free-riding experience? A key finding in a recent paper by Nalbantian and Schotter (1997) is that the performance of different group incentives is strongly affected by the previous history of the group - in particular by its previous contribution „norm“. This suggests that prior free-riding experience might well inhibit the performance of the mechanism. Figure 1b and Table 2 show the average contributions of groups 13-18 of M1. These six groups participated in M1 after they experienced C1. Subjects in C1 did not know that they will be in a M1-session afterwards. As one can see in Figure 1b the C1-data exhibit the usual declining pattern although contribution levels are rather high (on average above 50 percent). There is a very pronounced endgame effect of 30 percentage points from period 9 to period 10. Despite this severe decline in contribution levels in the last period, subjects in period 1 of M1 („period 11“) immediately „jump“ to higher contribution levels. Subjects in the first period of M1 contributed on average more than 14 tokens to the public good (compared to 4.2 tokens in period 10 of C1 before). The mean contribution in M1 was in each period above the mean contribution in the corresponding period of C1. The confidence bounds in Figure 1b also indicate that group behavior is considerably more stable under the mechanism.

In the second part of Table 2 we give a summary description of groups 13-18 of M1. As a comparison with groups 1-12 reveals, average contributions over all ten periods are slightly lower in groups 13-18 but the difference is not significant (Median test, $p = 0.62$). In the last three periods average (and median) contributions are almost identical to the contributions in groups 1-12. In particular, equilibrium play is again the prevalent behavior. Thus, groups 13-18 basically replicate the behavior of groups 1-12 of M1, i. e., the performance of the mechanism is not inhibited by the free-riding experience.

Before we consider questions of group size we take a closer look at the behavior of individual subjects. So far we mainly concentrated on average behavior within and across groups. From a policy viewpoint the group seems to be the most important unit of observation because one would like to know how the mechanism affects collective performance. Yet, from a game-theoretic perspective it is also interesting to know whether individual subjects are far from the Nash equilibrium prediction or whether they are close. That average and individual behavior may differ significantly is, for example, indicated by the experiments of Walker, Gardner and Ostrom (1990). Their data show that the average behavior of all groups together is reasonably well described by the Nash prediction although the Nash equilibrium has no drawing power at the individual level. With regard to our experiments Table 2 already provides a first indication that individual equilibrium play occurred quite frequently. During the last 3 periods in 13 of the 18 groups who participated in M1 the median contribution is exactly 20 and the average contribution of all groups together is larger than 18 tokens. This already indicates that a large fraction of subjects played close to the equilibrium of $g_i = 20$.

To shed more light on this issue we have computed the relative frequency of subjects who deviate by a certain percentage of their endowment from the equilibrium choice. The deviation has been measured by the absolute value of the difference between the equilibrium strategy and the average contribution of an individual subject. The result of this computation is displayed in Figure 2. 64 percent of the subjects deviate *at most* by 10 percent from the equilibrium, roughly 15 percent deviate between 11-20 percent while the rest of the subjects deviates by more than 20 percent. Thus, the big majority of subjects plays close to the equilibrium under the mechanism.

Figure 2: Relative frequency of subjects who deviate from equilibrium
Mechanism treatment *at most* by *x* % of their endowment



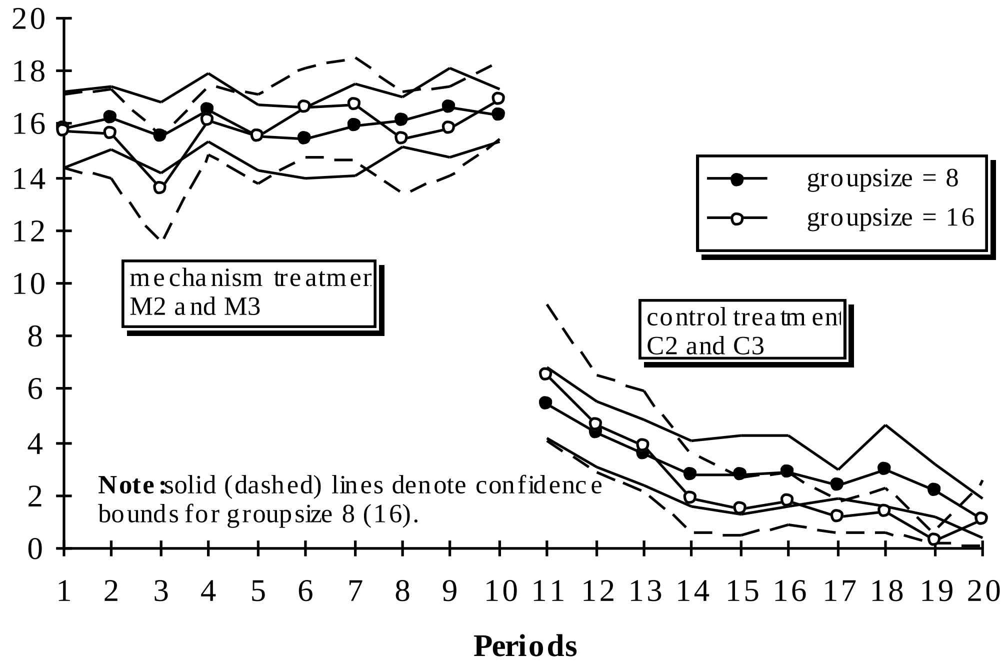
4.2 Does group size matter?

In this section we report the results of the C2-M2 and the C3-M3 treatments in which we increased the group size to $n = 8$, and $n = 16$, respectively. In all these treatments each group participated first in the mechanism treatment without knowing that afterwards there will also be a control treatment. After period ten of the mechanism treatment, subjects were told that there will be a new experiment.

Figure 3 depicts the evolution of average contributions for group sizes of $n = 8$ and $n = 16$. Table 3 shows the contribution behavior of groups 1-9 where group size was $n = 8$ and groups 10 and 11 where group size was $n = 16$. As in the mechanism treatment with $n = 4$ (see Figure 1a) subjects in larger groups start in period 1 with an average contribution of roughly 16 tokens. However, in contrast to the $n = 4$ case there is no increase in average contributions over time when the group size is larger. Instead, there are small fluctuations around a contribution level of 16 tokens throughout the ten periods. In period ten the average contribution is 16.3 tokens if $n = 8$ and 16.9 tokens in the $n = 16$ case. Figure 3 and Table 3 also show that contributions in groups with *n = 16* are roughly the same as those in groups with *n = 8*.

In the first period of the control treatments there is a very large drop in contributions to approximately 6 tokens. Contributions in the control treatments continue to decline until they, finally, reach less than 2 tokens in period twenty. In the last period 75 percent of the subjects in C2 and 84 percent of the subjects in C3 play *exactly* the Nash equilibrium of $g_i = 0$. This sharp contrast between the mechanism treatment and the control treatment indicates that the mechanism is very effective in an environment that creates an enormous free-rider problem in the absence of the mechanism.

Figure 3: The effects of group size



Yet, the comparison between Figure 1a and Figure 3 as well as between Table 2 and Table 3 also shows that the performance of the mechanism is slightly lower at a larger group size. To investigate whether these differences are significant we conducted a nonparametric Mann-Whitney test with group averages in period ten of M1 (*n = 4*) and M2 (*n = 8*) as units of observation.[16] There is weak evidence (p = 0.081, one-tailed) that the null hypothesis of equal average contributions can be rejected in favor of the alternative that groups with *n = 4* contribute more. However, on the basis of a more conservative Median test the null hypothesis of equal medians cannot be rejected (p = 0.21, one-tailed). Taken together we

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16 Due to the small number of group observations in M3 we cannot compare this treatment statistically with M1 or M2.

interpret this as weak evidence that the mechanism's performance slightly decreases if the group size rises from *n = 4* to *n = 8*. Yet, Figure 3 also suggests that there is no further decrease in the performance of the mechanism if the group size rises to *n = 16*.

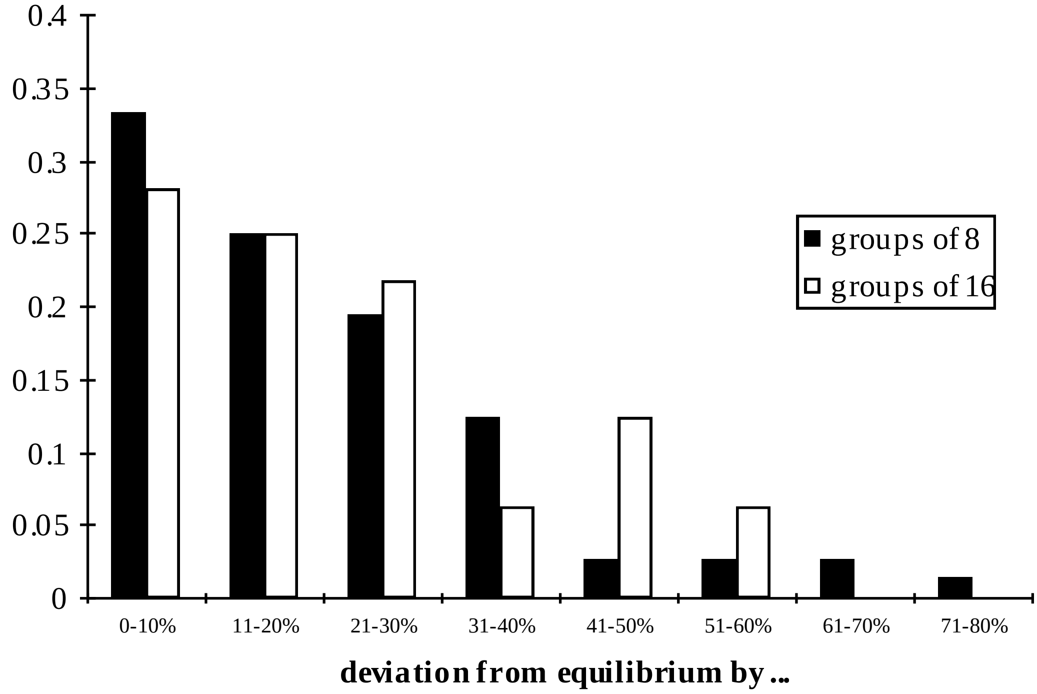
Table 3: Summary of group decisions (= token contributions to the public good) in the mechanism treatment with groups of 8 and 16 subjects

Group	**mean period 1 - 10**	**mean period 8 - 10**	**median period 8 - 10**
1	13.1	13.3	13
2	16.5	17.6	18
3	17.1	15.8	20
4	16.9	17.0	19
5	16.7	17.3	20
6	15.9	18.3	20
7	17.3	17.4	20
8	15.9	16.4	18
9	14.7	14.0	15
total of groups 1-9	16.0 = 80 percent	16.4 = 82 percent	19 = 95 percent
10	16.7	17.0	19.0
11	15.0	15.1	16.0
total of groups 10 and 11	15.8 = 79 percent	16.1 = 80.5 percent	18.0 = 90 percent

Note: Groups 1 to 9 (10 and 11) consist of 8 (16) group members. Percentage rates are calculated with respect to the equilibrium of 20 tokens.

This interpretation is confirmed if we look at individual subjects' deviations from equilibrium play (see Figure 4). It is still the case that the fraction of subjects who exhibit only small deviations (in the range of 0 - 10 percent) is largest. However, compared to subjects' deviations in the M1 treatment (see Figure 2) the fraction which deviates by more than 10 percent from the equilibrium is now larger.

Figure 4: Relative frequency of subjects who deviate from equilibriu
at most by *x* % of their endowment



4.3. The mechanism in a nonlinear environment (interior equilibria)

In this section the results of the C4-M4 and the C5-M5 treatments, in which interior equilibria were implemented, are reported. Groups 1-12 of M4 and all groups of M5 participated first in the mechanism treatment (M4, M5). After the mechanism treatment the *same* subjects participated in the control treatment (C4, C5). Subjects in the mechanism treatment did not know that they will play another experiment afterwards. For groups 13-18 of M4 we reversed the order of play. This allows a robustness check of the mechanism in this more complex environment. Since we thought that in a nonlinear environment it might take longer to approach the equilibrium we increased the number of periods in both treatment conditions to 20.

Figure 5a shows the evolution of average contributions in groups 1-12 of M4 over time. The figure displays the remarkable fact that average contributions are very close to the equilibrium already from period 1 onwards. Throughout the M4-session they fluctuate a little bit around the equilibrium of 30 tokens. The second salient fact is that the 95 percent confidence bounds are rather small and contain the equilibrium in almost all periods. Hence, the null hypothesis of equilibrium play cannot be rejected. Thirdly, the evidence from C4 indicates that contributions drop immediately if the mechanism is removed and approach, finally, the Nash

Figure 5a: Evolution of mean contributions (and confidence bounds) w
and without the mechanism

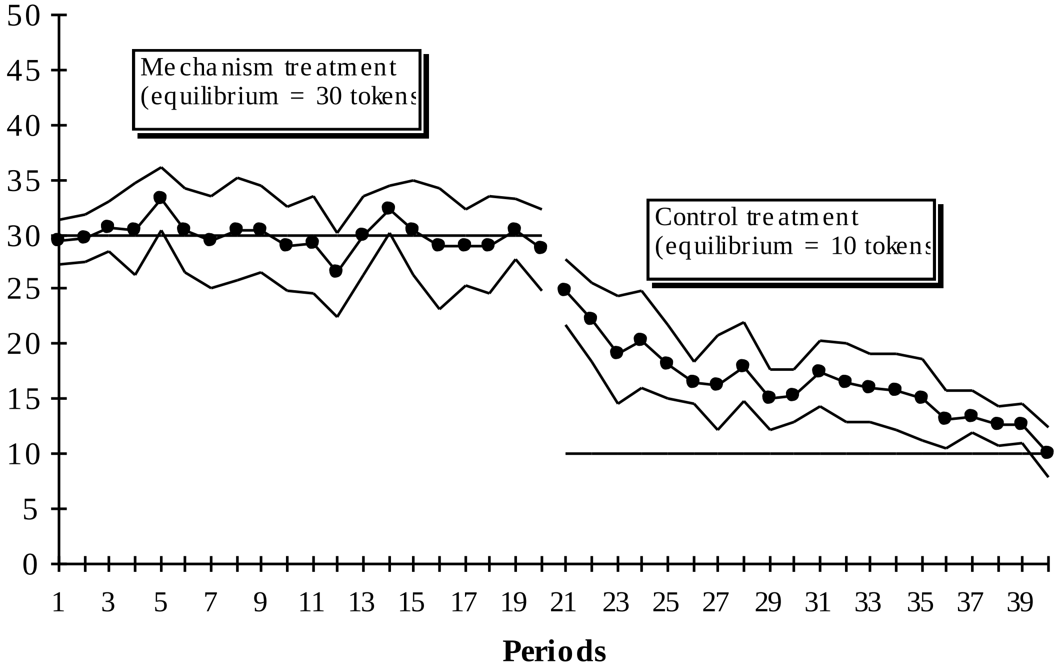


Figure 5b: The robustness of the mechanism - mean contributions (an
confidence bounds) in M4 (groups 13-18) after the experience of C4

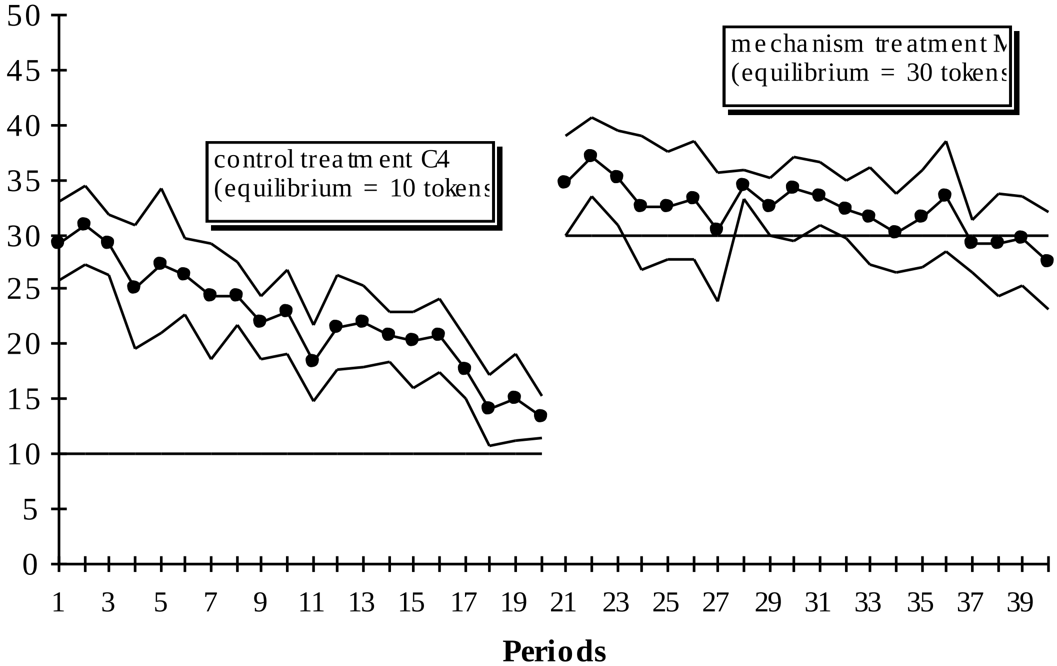


Table 4: Summary of group decisions (= token contributions to the public good) in the mechanism treatment with an interior equilibrium

Group	mean period 1 - 20	mean period 15 - 20	median period 15 - 20
1	36.5	40	40
2	24.9	27.3	20.5
3	28.9	26.3	29.5
4	26.7	25.2	22
5	30.6	35.7	43.5
6	30.7	28.6	30
7	24.8	28.1	31
8	33.2	29.9	35
9	32.7	35	39
10	26.7	24.5	25
11	32.2	26.8	27
12	30.3	25.3	25
total of groups 1-12	29.8 99.3 percent	29.4 98 percent	30 100 percent
13	30.4	27	33.5
14	37.1	32.4	29
15	33.7	28.1	30
16	30.1	30.9	35.5
17	30.1	31.5	39
18	32.1	30.5	30
total of groups 13-18	32.2 = 107.2 percent	30.1 = 100.3 percent	30 = 100 percent
19	31.3	31.0	35
20	35.8	32.8	40
21	27.9	26.3	25
22	28.6	26.8	21
23	37.7	36.8	40
total of groups 19-23	32.3 = 107.7 percent	30.7 = 102.3 percent	31.5 = 105 percent

Note: Groups 1 to 18 (19 to 23) took part in the homogeneous (heterogeneous) treatment. Groups 1-12 (13-18) first played M4 (C4), then C4 (M4). Groups 19-23 first played M5 and then C5. Percentage rates are calculated with respect to the equilibrium of 30 tokens.

equilibrium of 10 tokens. The average and modal choice in period 20 of C4 was exact equilibrium play at $g_i = 10$. A Wilcoxon signed ranks test confirms (p = 0.002, one-tailed) what Figure 5a already suggests, namely, that contributions are significantly higher in the mechanism treatment.

Figure 5b presents the evolution of average contributions when subjects first play the control treatment C4. As in the control treatment of Figure 5a there is slow convergence to the Nash equilibrium of 10 tokens.[17] In contrast to this slow convergence in C4, contributions in the mechanism treatment again are close to the equilibrium from the early periods of M4 onwards. A Mann-Whitney test shows that contributions in groups 1-12 are not significantly different from the contributions of groups 13-18 (p = 0.302). This confirms our finding in section 4.1 where we have seen that the mechanism also performs well when subjects have previous free-riding experience.

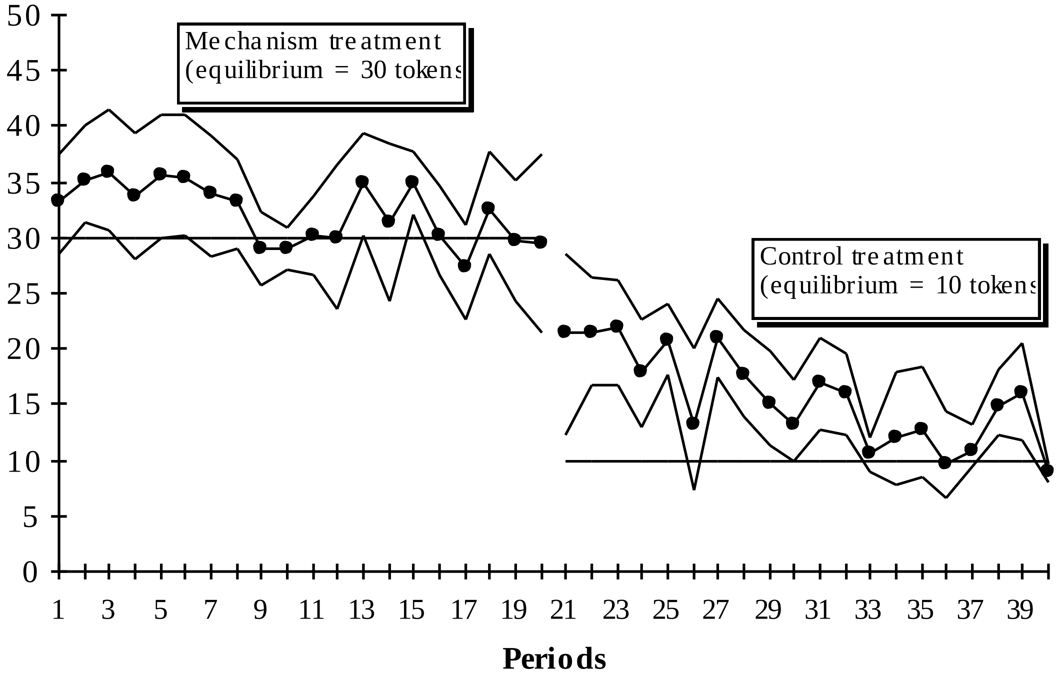
Taken together, the behavior of groups in M4 indicates that there is no overcontribution in the mechanism treatment. The average contribution over all 18 groups and all periods is 30.6 tokens which is only 2 percent above the equilibrium. For the last five periods the average contribution is 29.6 tokens which is only 1.3 percent below the equilibrium. The median contribution in the last five periods is even *exactly* at the equilibrium. This indicates that the Nash equilibrium is a remarkably good predictor of group behavior in the mechanism treatment with homogeneous subjects.

In C5 and M5 we implemented an interior solution with heterogeneous payoff functions. Here the equilibrium required subjects to choose different contribution levels. However, the mean equilibrium contribution of groups was again 10 tokens for C5 and 30 tokens for M5. Figure 6 shows how contributions evolve over time under these conditions. The Nash equilibrium of 30 tokens is again a rather good predictor of group behavior although not quite as good as in the condition with homogeneous subjects. During the first periods of M5 there is some overcontribution. However, if we take all periods together the overcontribution is not statistically significant. A χ^2-test reveals that mean contributions are not systematically above or below 30 tokens (p = 0.37). Moreover, contributions in M5 are not significantly different from contributions in M4 (Mann-Whitney test, p = 0.55). Towards the end of the mechanism treatment M5 contributions come very close to the equilibrium (see Figure 6 and Table 4). During the last five periods the average contribution is 30.7 tokens which is only 2.3 percent above the equilibrium. The median contribution in this time interval is 31.5. In period 21, when the mechanism is removed, there is a large drop in contributions. In C5 contributions

[17] Our data in C4 replicate the results of the experiments by Keser (1996) and Sefton and Steinberg (1996).

finally also approach the equilibrium value although with some fluctuations around a decreasing trend.[18]

Figure 6: Evolution of mean contributions (and confidence bounds) w
and without the mechanism with heterogeneous preferences



Information regarding individual play in the treatments with interior solutions is presented in Figure 7. In the treatment with homogeneous players a little bit less than 40 percent of the subjects deviate by less than 10 percent from the equilibrium. A similar percentage of subjects deviates between 11 and 20 percent while the rest exhibits larger deviations. In the treatment with heterogeneous subjects roughly 35 percent of subjects show only small (≤ 10 percent) deviations and 25 percent deviate between 11 and 20 percent. Thus, at the individual level contributions are not as close to the equilibrium as in M1 (compare Figure 2 with Figure 7).[19] However, we find it remarkable that even in the rather complex environment of M4 and M5 the Nash equilibrium has a strong drawing power also at the individual level.

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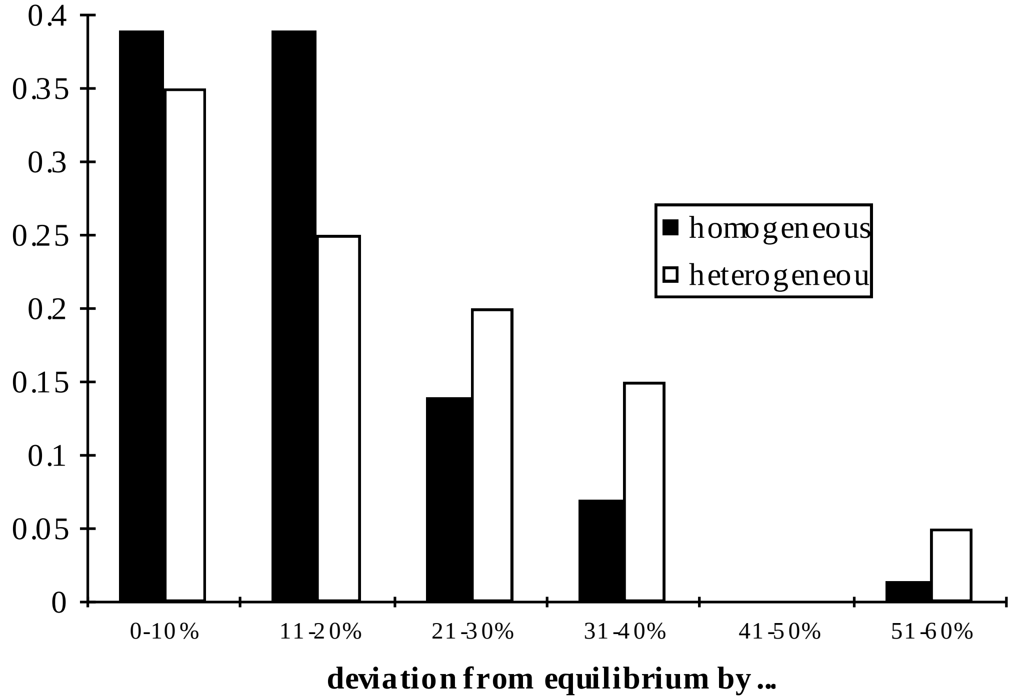
18 With regard to C5 and M5 one has to keep in mind that the number of independent observations (groups) is considerably smaller than in C4 and M4. Therefore, confidence bounds are larger in C5 and M5.

19 Note that the strategy space in the treatments with interior equilibria is $g_i \in \{0,1,...,50\}$ while in the treatments with corner equilibria it is $g_i \in \{0,1,...,20\}$. To render Figure 7 comparable to Figures 2 and 4 we always computed the deviation from equilibrium as a percentage of the total available endowment. Of course, in Figure 2 and 4 the total endowment coincides with the equilibrium contribution.

Figure 7: Relative frequency of subjects who deviate from equilibriu
at most by *x* % of their endowment



5. Summary

In this paper we examined the performance of the Falkinger (1996) mechanism for the provision of public goods. The results of our experiments indicate that the mechanism does quite well in the laboratory. In each of the implemented economic environments the mechanism caused an *immediate* and *large* shift towards an efficient solution. This suggests that little practical experience with the mechanism is necessary to induce a significant and large increase in contributions. If one compares the long run behavior in the control and the mechanism treatments the impact of the mechanism is even larger: In the control treatments we always observed a steady decline in contributions over time and towards the end the free-riding equilibrium exerts a strong drawing power. Contributions in the mechanism treatment remained rather stable at high levels or increased over time. Thus, in the long run the mechanism generates even larger efficiency gains because it is able to overcome the strong free-rider problem observed in repeated public good experiments.

From a game theoretic point of view the major difference between the control treatment and the mechanism treatment concerns the fact that the Nash equilibrium is a much better predictor of behavior in the mechanism treatment. In general, deviations from the Nash equilibrium are lower in the mechanism treatments. In the control treatments the Nash equilibrium is only a good predictor for the final periods while in the early periods we always observe substantial overcontribution. No such overcontribution occurs in the mechanism treatments.

This data pattern indicates that in the control treatment there are forces at work which inhibit quick adjustment to the Nash equilibrium. In our view the differences in the deviations from the equilibrium have to do with the position of the equilibria. In the control treatments the distance between the Nash equilibrium and the welfare maximizing solution is much larger than in the mechanism treatments, where it is even zero in many cases. Therefore, if subjects have a behavioral drive towards cooperation, the adjustment to the free-rider equilibrium is inhibited. In contrast, in the mechanism treatment such a behavioral drive speeds up the convergence to equilibrium play.[20]

From a policy point of view it is also interesting to know to what extent the public budget is actually involved under the mechanism. Although the public budget is always balanced by definition it may be considered as a further advantage of the mechanism if the actual tax and transfer payments per person are low. In reality a mechanism may be more easily accepted if the implied payments from and to the households are small. In our experiments the average tax or transfer payment per person as a percentage of a subject's endowment varies between 4 and 10 percent. This indicates that the volume of tax payments which has to be enforced by a central authority is relatively small.

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20 Since the fraction of groups and individuals that are close to the equilibrium is relatively large in all of our mechanism treatments the question arises why we observe considerably more equilibrium play than, for example, in Walker, Gardner and Ostrom (1990). We are not capable of providing a precise anwer to this question. However, we conjecture that part of the answer is due to the position of the equilibrium. In the Walker-Gardner-Ostrom-experiments the distance between equilibrium behavior and welfare maximizing behavior is larger than in our mechanism treatment. It is known from other studies (e.g., Brandts and Schram 1996, Fehr and Gächter 1997, Keser and van Winden 1997) that many subjects are conditionally cooperative, that is, they are willing to cooperate if others cooperate but they tend to retaliate if they are hurt by others. If the distance between equilibrium behavior and welfare maximizing behavior is large conditionally cooperative subjects are particularly tempted to achieve cooperation which contributes to individual deviations from the equilibrium. Moroever, since these attempts at implicit cooperation frequently fail there will be retaliatory actions which also contribute to individual deviations from equilibrium play.

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