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Public Goods Experiments

(followed by a comment by Claude Montmarquette)

Claudia Keser

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Cooperation in Public Goods Experiments*

(followed by a comment by Claude Montmarquette)¤

Claudia Keser†

Résumé / Abstract

Ce texte (Keser) présente une revue et une discussion des écrits de la littérature en économie expérimentale sur la coopération dans la production de biens publics. Le texte est suivi d'un commentaire (Montmarquette) qui met l'accent sur les applications économiques que l'on peut tirer de ces études.

This text (Keser) is a survey and a discussion of experimental studies on cooperation in public goods experiments. It is followed by a comment (Montmarquette) suggesting some economic applications from these experimental studies.

Mots Clés : Économie expérimentale, bien public, revue

Keywords: Experimental economics, public goods, survey

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* Corresponding Author: Claudia Keser, CIRANO, 2020 University Street, 25th floor, Montréal, Qc, Canada H3A 2A5 Tel.: (514) 985-4000 ext. 3014 Fax: (514) 985-4039 email: keserc@cirano.umontreal.ca
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¤ Claude Montmarquette is professor at the Département de sciences économiques de l'Université de Montréal and director of the "Human Resources" research group at CIRANO

† Universität Karlsruhe and CIRANO

1. Introduction

A public good has two distinctive characteristics. Its fundamental characteristic is non-rivalry in consumption. In the words of Samuelson (1954), "each individual's consumption of such a good leads to no subtraction from any other individual's consumption of that good." Another characteristic of a public good is that exclusion from its consumption is difficult. Thus, when it comes to the financing of a public good by private arrangements, individuals face a monetary incentive to free-ride on the contributions of others. According to economic theory, this leads to a Pareto inefficient provision of the public good (e.g., Cornes and Sandler, 1986). Social choice theory proposes sophisticated collective decision processes to achieve efficient provision of public goods (see Laffont (1987) for a survey). They are often complicated and difficult to apply. A simple tax-subsidy scheme has been suggested by Falkinger (1996). In a series of experiments, Falkinger et al. (*forthcoming*) show that with this mechanism an almost efficient public goods provision can be achieved. But, although this mechanism is easy to apply, it requires a central authority which can enforce taxes.

Actually, the role of government is often justified by the necessity to produce goods and services that the private sector is not inclined to produce, i.e. public goods.[1] Government provision of public goods, financed by lump-sum taxes, is, however, not necessarily more efficient than private provision of public goods (Bergstom, Blume and Varian (1986), for example, suggest various reasons why private provision would sometimes be more efficient than public provision). We observe many cases of government provision of public goods that do not appear very successful. The public funding of environmental protection measures (e.g., those to comply with the Kyoto protocol), of measures against contagious diseases or of fundamental scientific research are such examples. These are examples relating to public goods which are of global nature. Public goods may also be of local access. Consider, for example, cultural institutions, such as theaters, operas or museums. In countries like France and Germany these cultural institutions are publicly financed. They often have to put up with a very small budget while their counterparts in the United States, which are largely financed by private donations, do very well. Consider also the public broadcasting service (PBS) in the United States. PBS is a private, nonprofit corporation whose members are America's public TV stations. It provides quality educational programs, products and services for use in homes, schools, and workplaces. It is almost entirely financed by voluntary contributions. In contrast to this, public TV stations in Canada, which are mainly financed by taxes, seem to do less well in quality and budget. They probably could do better with voluntary contributions. Considering the large number of Canadian underwriters to PBS in the United States, we have evidence that Canadians are willing to make voluntary contributions to finance quality broadcasting.

There is a lot of empirical evidence that people are willing to make substantial voluntary contributions to the funding of public goods. Probably, the prediction of economic theory

[1] Another school of thought claims that most of the government expenditures are for the production of private goods that are publicly financed (Aranson and Ordeshook, 1981). Montmarquette (1996) estimates that in Canada actually only about 15 percent of the public expenditures are for the provision of public goods.

regarding the private provision of public goods is too pessimistic. Experimental economics allows us to examine this question analyzing human behavior in well controlled public goods situations in the laboratory.

The typical public goods experiment

In an experiment, the public good situation is usually presented in an abstract way. Typically, it is a symmetric game with n players. Each player i is endowed with a number of tokens, e, which have to be allocated between two investments, a private and a collective investment. Be x_i the number of tokens that player i allocates to the private investment, and y_i the number of tokens that he allocates to the collective investment, with $x_i, y_i \in \{0, 1, 2, ..., e\}$ and $x_i + y_i = e$. The profit function of player i, Π_i (.), which depends on his private investment and the sum of all players' contributions to the collective investment, typically is linear:

$$\Pi_i \left(x_i, \sum_{j=1}^{n} y_j\right) = rx_i + k\sum_{j=1}^{n} y_j$$

with the parameters r and k satisfying the constraints (1) $r > k$ and (2) $nk > r$. In other words, each of the investments yields player i a constant return per token. The return per token in the private investment, r, is larger than the individual return per token in the collective investment, k (constraint 1). However, the return of a token in the collective investment for all players together, nk, is larger than the individual return per token in a private investment (constraint 2).

The linearity of the profit function and constraint (1) imply that, in game-theoretic terms, it is a dominant strategy for each player i to contribute all of his endowment to his private investment and nothing to the collective investment: whatever the other players' investment decisions, his personal profit is always maximized with this strategy. If the game is played T times by the same players, we find the game-theoretical solution by backward induction. In the subgame perfect equilibrium of the game, each player allocates in each round t (t = 1, ..., T) all of his tokens to his private investment and nothing to the collective investment. However, due to constraint (2), the profit of all players together is maximized if all of the tokens are allocated to the collective investment. Thus, the group optimum is realized if, in each round t, each player allocates all of his tokens to the collective investment.

Note that, in this game, the return per token contributed to the collective investment which accrues to each of the players represents a public good. The game-theoretical solution predicts zero contribution to the funding of this public good—which is collectively inefficient

Extensive surveys of the early experimental studies on voluntary contributions to public goods are presented by Ledyard (1995) and Davis and Holt (1994). They conclude that, in early rounds of the public goods game, subjects tend to make considerable contributions to the collective investment. The contribution level decreases, however, over time until it is almost zero by the final round. Many experimental studies replicate these results but also show that the average contribution level depends on several factors. These factors might be parameters of the model or other factors that are irrelevant with respect to the game-theoretic prediction. In a recent survey , Holt and Laury (*forthcoming*) try to explain these so-called *treatment effects* in voluntary contributions experiments by four types of models that incorporate (1) generalized preferences, (2) noisy decision making, (3) evolution and adaptation, or (4) cooperation and signaling.

The major purpose of this article is to present, based on several experiments, an interpretation of subjects' behavior in public goods experiments in terms of cooperation. This article is not meant to present another survey on the literature on public goods experiments. Before focusing on the issue of cooperation, we will show, in Section 2, the robustness of the phenomenon of over-contribution relative to the game-theoretic prediction in two important modifications of the public goods model: first, we consider a public good situation in which each player's dominant strategy is to contribute some of his endowment to the public good (Keser, 1996); second, we consider a model where the provision of the public good is uncertain (Dickinson, 1998). Then, in Section 3, we will elaborate how reciprocity is used in public goods situations as an instrument to achieve cooperation. I will present the interpretation of subjects' behavior in terms of conditional cooperation given by Keser and van Winden (*forthcoming*). This interpretation will be complemented by the results of an experiment in which subjects designed complete behavioral plans for playing a public goods game (Keser, 1999). In Section 4, we will discuss the opportunity to punish others individually as another instrument to increase cooperation (Fehr and Gächter, 1999). A new design of public goods experiments in which the interaction structure is flexible (Ehrhart and Keser, 1999, *in preparation*) is presented in Section 5. Players have the opportunity to migrate from one group to another. These experiments allow us to extend our examination of subjects' behavior in public goods situations in two ways: first, we can examine the effect of mobility on the level of voluntary contributions to public goods. Second, these experiments allow us to elucidate aspects of human behavior which remain hidden in experiments with a fixed interaction structure. Both free-riding and conditional cooperation appear to be active principles in the sense that the free-riders seek to take advantage of the contributions of others and that cooperators try to form groups with other cooperators. In Section 6, I will briefly discuss why, in contrast to public goods, cooperative outcomes are more difficult to achieve in common pool resource situations (Ostrom, Gardner and Walker, 1994; Keser and Gardner, 1999). Section 7 concludes the article.

2. Robustness of the voluntary contributions phenomenon?

The phenomenon of voluntary contributions to public goods when the theory predicts zero contribution is considered a stylized fact. As shown by Isaac, Walker and Williams (1994), even in very large groups subjects tend to make considerable voluntary contributions. In this Section, I want to present two experimental studies on modifications of the typical public goods game: one where the dominant strategy solution prescribes some contribution to the public good, the other where the public good provision is uncertain. We will see that the voluntary contributions phenomenon is robust also to these modifications.

2.1 Partial contribution to the public good is a dominant strategy

The typical public goods game is designed such that each player's dominant strategy is to contribute nothing to the public good. In such a game, if we assume that subjects might err in their decision making, errors necessarily lead to positive contributions to the collective good. This is due to the fact that the game-theoretical solution of no contribution lies at the border of the strategy space. Thus, the over-contributions that we typically observe in public goods experiments might simply result from subjects' error making (Andreoni, 1988, 1995; Rabin, 1998).

Therefore, I designed a public goods game which has a dominant strategy solution in the interior of the strategy space. In Keser (1996) I present experimental results on this game with the parameters $n = 4$, $e = 20$, and $T = 25$. It distinguishes itself from the typical public goods game by the fact that the individual profit function is not linear but quadratic in one's private investments. The profit function of player i is

$$\Pi_i \left(x_i, \sum_{j=1}^{4} y_j\right) = 41x_i - x_i^2 + 15\sum_{j=1}^{4} y_j$$

In contrast to the typical game, returns per token in the private investment are decreasing in the total number of tokens allocated to the private investment. The subjects were informed about the profit function only indirectly by Table 1. This table presents the return of each token allocated to the private investment. It is easy to see in this table that the last 7 tokens contributed to one's private investment yield a return below 15, the individual return per token in the collective investment. It is, thus, a dominant strategy for each player to contribute 7 tokens to collective investment and to allocate the remaining 13 tokens to his private investment. The profit of the entire group is maximized, however, if each player contributes all of his endowment to the collective investment (as the group return of a token in the collective investment, 4 times 15, is larger than 40, the highest return of a token in the private investment).

The experiments were conducted in a computerized way with 48 students at the University of Amsterdam. We observed 12 independent groups of 4 subjects each. After each round, each subject was informed about his return from each investment and the sum of tokens contributed to the collective investment by the other players in his group. At the end of the experiment, each subject was paid in cash depending on his cumulated profit after the 25 rounds of the game.

Table 1: Return from tokens allocated to the private investment

Token	Return from that token	Token	Return from that token
1st	40	11th	20
2nd	38	12th	18
3rd	36	13th	16
4th	34	14th	14
5th	32	15th	12
6th	30	16th	10
7th	28	17th	8
8th	26	18th	6
9th	24	19th	4
10th	22	20th	2

On average we observe, with respect to the dominant strategy, an over-contribution to the collective investment of about 25 percent. Figure 1 shows the time path of the average contributions to the collective investment. In each round the average contribution is above 7, the dominant strategy solution. Furthermore, the average contribution of each independent group is above the dominant strategy solution. Thus, we observe a statistically significant over-contribution to the public good (χ^2 test, 1 percent significance level). It is unlikely that this over-contribution results from accumulated errors. In this game with an interior dominant strategy solution, subjects might make errors to both directions around the dominant strategy.[2] The observed over-contribution seems less important than in the typical public goods experiments but it is statistically significant. The same result has been found by Vergnaud, Willinger and Ziegelmeyer (1999) who replicated this experiment in France. Also Sefton and Steinberg (1996), van Dijk, Sonnemans and van Winden (1997), and Falkinger, Fehr, Gächter and Winter-Ebmer (*forthcoming*) confirm this result in similar experiments.[3]

[2] Anderson, Goeree and Holt (1998) apply their logit equilibrium model to the game presented in Keser (1996) to show that the interior dominant strategy solution need not imply that, on average, errors cancel out.

[3] Laury and Holt (*forthcoming*) provide a survey on public goods experiments with equilibrium solutions in the interior of the strategy space.

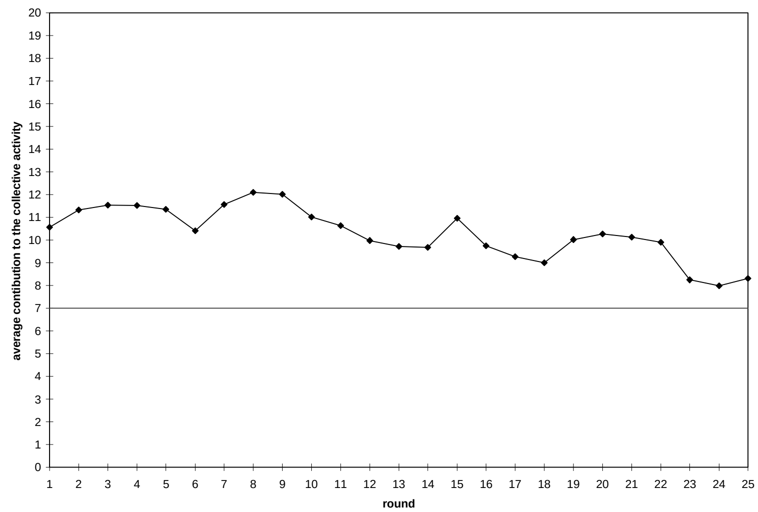

Figure 1: Time path of the average contributions to the collective investment (Keser 1996)

2.2 Uncertain Group Payoffs

In the typical public goods model the amount of the public good provided depends on the contribution of all players, and this provision level is realized with certainty. In real life, we observe many situations where the public good provision is uncertain. Consider, for example, work teams (such as a soccer team) where the individual compensation is tied to group results but the correlation between effort and results is imperfect. Motivated by such considerations, Dickinson (1998) presents experiments on public goods games with uncertain group payoffs.[4] He introduces two variations of the typical public goods model that he calls the "uncertainty" model and the "incentive" model. In the uncertainty model the public good is provided with a fixed probability below one. In the incentive model the probability of the provision of the public good increases in the contribution level.

The parameters of his model are n = 5, e = 15, and T = 7. The profit function of player i is

$$\Pi_i \left(x_i, \sum_{j=1}^{5} y_j \right) = x_i + pk\sum_{j=1}^{5} y_j$$

where p is the probability with which the public good is provided, and k the individual return per token in the collective investment. In the baseline experiment p = 1 and k = 0.5, and in the

[4] The uncertainty in his model is different from the one in threshold models in which a certain level of contributions is needed for the provision of a public good (e.g., Isaac, Schmidtz and Walker, 1988). A survey of experimental results on threshold public goods models is given by Ledyard (1995)

uncertainty experiment p = 0.7 and $k = 0.5$. In the incentive experiment, the probability with which the public good is provided depends on the sum of all players' contributions to the collective investment, $p = 0.01\sum y_j$, and $k = 0.666$. Under the assumption of risk-neutrality it is, in the baseline and the uncertainty model, a dominant strategy for each player to contribute nothing to the public good. In the incentive model there exit two Nash equilibria, one equilibrium in which no player contributes anything to the public good, and another equilibrium in which each player contributes all of his token endowment to the public good. In all three models the collectively optimal outcome is obtained if each player contributes all of his token endowment to the public good.

The experiments were conducted as classroom experiments at the University of Arizona. In each of ten sessions, 5 subjects first played a sequence of 7 rounds of the baseline model, then a sequence of seven rounds of the uncertainty model, and then a sequence of 7 round of the incentive model. On the aggregate, the contribution levels in the uncertainty and in the incentive model show no significant difference with respect to the contribution level in the baseline model. In all three models, subjects make significantly positive contributions to the public good. In each of the three models contributions show the typical downward trend. Thus, the typical over-contribution result applies also to situations where the group payoff is uncertain.

3. Reciprocity as an Instrument to achieve cooperation

Many explanations for the voluntary contributions phenomenon can be found in the literature. Most of them are in terms of generalized preferences, such as warm glow preferences, altruism, or reciprocal altruism. Warm glow preferences imply that the pure act of contributing to a public good increases a subject's utility (Andreoni, 1990), while altruistic preferences imply that a subject puts positive value on the payoff of others (Becker, 1974). We talk about reciprocal altruism when a subject's preferences on the payoffs of others depend also on the behavior, motivations, and intentions of the others. "If somebody is being nice to you or others, you are inclined to be nice to him; if somebody is being mean to you or others, you are inclined to be mean to him." (Rabin, 1998, p. 21). While this definition of reciprocity is motivational, Axelrod (1984) defined reciprocity in terms of behavior without reference to preferences: cooperation is reciprocated with cooperation and defection is reciprocated with defection. In the following, I have this definition in mind when I talk about reciprocity. In public goods experiments we often observe subjects to behave reciprocally. We argue that reciprocity is used as an instrument to achieve cooperation with others. This is elaborated in Keser and van Winden (*forthcoming*) where we present an interpretation of subjects' behavior in terms of conditional cooperation which is characterized both by reciprocity and forward looking aspects. This interpretation finds strong support in strategies submitted by subjects for participation in an international computer tournament (Keser, 1999).

3.1 Conditional Cooperation

In Keser and van Winden (*forthcoming*) we present experiments in which the repetition of the public goods game is effectuated in two different ways. In the so-called *partners situation*, players interact in the same groups during the entire game, while in the so-called *strangers situation* the groups are randomly formed anew in each round.[5] The game-theoretical prediction is the same in both situations: for the typical public goods game, it is zero contribution to the collective investment in each round. The public goods game has the parameters $n = 4$, $e = 10$, $T = 25$, and the profit function

$$\Pi_i \left(x_i, \sum_{j=1}^{4} y_j\right) = 10x_i + 5\sum_{j=1}^{4} y_j$$

The experiments were organized in a computerized way with 160 subjects at the University of Amsterdam. With 40 subjects in the partners situation we observed 10 independent partners groups of 4 subjects each, and with 120 subjects in the strangers situation we observed 6 independent strangers populations of 20 subjects each. After each round of the game, each subject was informed about his return from each investment and the sum of tokens contributed to the collective investment by the other players in his group. At the end of the experiment, each subject was paid in cash according to his cumulated profit after the 25 rounds of the game.

We observe that partners contribute on average 45 percent of their endowment to the public investment. This is significantly above the strangers' average contribution of 19 percent of their endowment (Mann-Whitney U test, 5 percent significance level). This difference is significant from the first round on. Figure 2 shows the time paths of the average contributions in the partners and the strangers situation. The contribution level of partners is in each repetition above the contribution level of strangers. Interestingly, only in the strangers situation do we observe a continual downward trend. In the partners situation contributions fluctuate on a relatively high level until they decrease strongly toward the end of the game.

[5] Andreoni (1988) inspired the comparison of subjects' behavior in the partners and in the strangers public goods situation. His hypothesis is that partners should contribute more than strangers. A rational player in the partners situation could—in contrast to the strangers situation—have a strategic interest in the sense of Kreps et al. (1982) in contributing his tokens to the public investment. If, for example, he is not sure whether or not the others in his group are conditionally cooperative, he could have an interest, in early repetitions of the game, to build a reputation of being a conditionally cooperative type himself in order to free-ride on the other players' contributions toward the end of the game. In contrast to this hypothesis, Andreoni's experimental result show a higher contribution level in the strangers situation than in the partners situation. He has no explanation for this counter-intuitive result, which is based on only two independent strangers observations. It is, thus, not surprising that several other studies have followed to examine the partners-strangers phenomenon (Weimann, 1994; Croson, 1996; Palfrey and Prisbrey, 1996; Burlando and Hey, 1997). A survey is given by Andreoni and Croson (*forthcoming*).

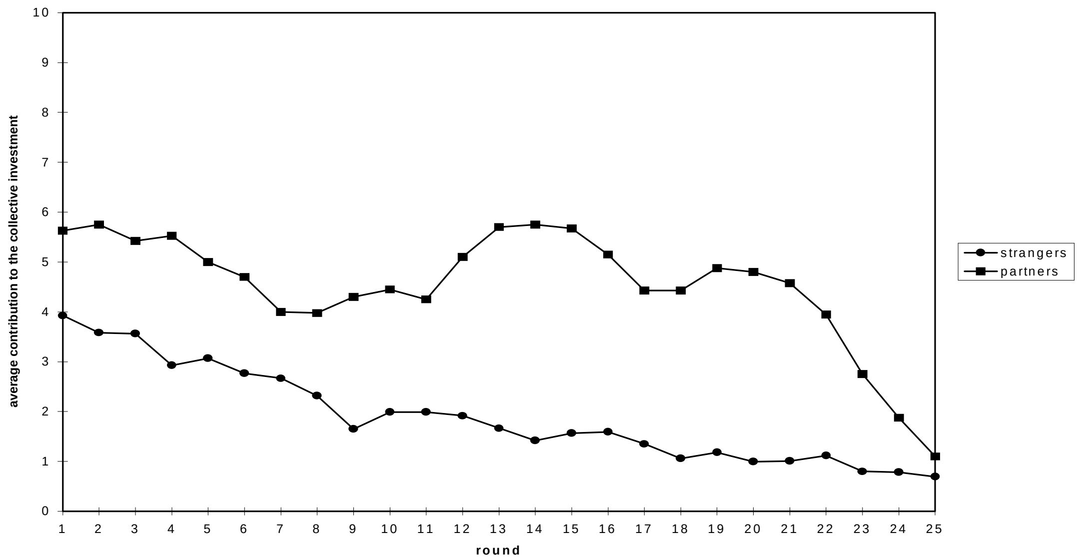

Figure 2: Time paths of the average contributions to the collective investment of partners and strangers (Keser and van Winden forthcoming)

We suggest an interpretation of subjects' behavior in terms of *conditional cooperation*. We distinguish between two aspects: one is *future-oriented behavior*; the other is *simple reactive behavior*. As future-oriented behavior we define aspects of subjects' behavior that are induced by their perception of future interaction. Evidence of this type of behavior particularly shows up in the partners situation where the contribution level tends to fall sharply in the final rounds. Possibly, near the end of the game, subjects realize that investment in their relationship with the others is not worthwhile any longer. Or, they anticipate such a reasoning by the others. Other evidence of future-oriented behavior is provided by the fact that already in the first round of the game we observe a significant difference in the contribution levels of partners and strangers. An explanation can be found in Keser (1999), discussed below, where subjects are observed to signal in the first rounds their willingness to cooperate, and then reciprocate the observed contribution of the others until almost the end of the game. Intuitively, it is plausible that the propensity to signal a willingness to cooperate is stronger in a partners situation, where subjects interact in the same group during the entire game, than in a strangers situation, where groups are randomly formed in each round. Furthermore, the literature suggests that individuals show a propensity to identify with the group they belong to. As a consequence, an interest in group success is substituted for or added to their interest in individual success (see, for example, Brewer and Kramer, 1986; Dawes and Thaler, 1988; Dawes, Van de Kragt and Orbell, 1988; Simon, 1993; Taylor and Moghaddam, 1994). Obviously this factor is more relevant for the partners situation than for the strangers situation.

The second aspect of conditional cooperation concerns reactive behavior. Supportive in this respect is the above mentioned observation in Keser (1999) that subjects' behavior in a public good game is oriented toward the average behavior of the other group members in the previous round. This kind of behavior is in line with the principle of reciprocity that was used by Axelrod (1984) as an explanation for the observed cooperation in a prisoner's dilemma situation where subjects tend to reciprocate cooperation with cooperation and defection with defection. In Keser and van Winden (*forthcoming*) we formalize reciprocity in a qualitative decision rule:[6] if a subject intends to change his decision from one round to the next, he changes it in the direction of the other group members' contribution in the previous round. This means that he increases his contribution if it was below the average of the others, and he decreases his contribution if it was above the average. We observe that subjects significantly tend to obey this rule. Interestingly, this evidence appears equally strong in both the partners and the strangers situation (about 80 percent of the observed changes are in the right direction).

Note that only in the strangers condition do we observe a large number of free-riders (defined, in a weak sense, as subjects who contribute nothing to the collective investment in the majority of rounds). Free-riders' behavior does not violate our qualitative rule of reciprocity as they do not change their decisions from one round to the next. Their contribution is below or equal to the average contribution of the others. At the same time, those subjects who have contributed more than others tend to decrease their contributions. This offers an explanation of the observed continual decay in the average contribution level in the strangers situation.

Thus, we give a dynamic interpretation of subjects' behavior in the public good situation in terms of conditional cooperation. In contrast to some static theories of cooperative behavior, as the theory of reciprocity (Rabin, 1993), the theory of equity (Bolton and Ockenfels, *forthcoming*), or the theory of inequality aversion (Fehr and Schmidt, 1999), with which our experimental results are also compatible, our theory can explain the observed differences in the behavior of partners and strangers.

3.2 Strategic Behavior

Selten (1967) presents a strategy method of experimentation which directly reveals subjects' strategies. Subjects, preferably with some experience in playing the considered game, are asked to design complete and exact behavioral plans that prescribe a decision for each situation that may arise in the game. The experiment presented in Keser (1999) is an application of this strategy method to the above presented public goods game with an interior dominant strategy solution (as in Keser 1996).

I invited academic economists, mathematicians and psychologists all over the world to participate in a strategy tournament. They received an invitation brochure in which the game and the tournament instructions were described in detail. Fifty scientists from 13 different countries submitted their strategies for playing the public goods game. The strategies were submitted as flow-charts which were translated by myself into computer code. Each participant submitted three strategies, one strategy for each of three consecutive simulation rounds. In a simulation, the

[6] This definition is inspired by the learning direction theory first presented by Selten and Stoecker (1986). See also Selten (1998).

submitted strategies were combined in all possible groups of 4 strategies to play the 25-period game. The success of a strategy in a computer simulation was measured by its average profit over all plays in which it was involved. After a simulation, results were communicated to the participants. Each participant received an anonymous list of ranked simulation profits and records of 20 randomly chosen plays. The record of a play documented, for each round of the game in question, the strategy's allocation decision, its payoff from each investment, and the number of tokens contributed by the entire group to the collective investment. In each simulation round, one of the participants was randomly chosen for cash payment depending on his strategy's success. Furthermore, the knowledge that the list of rank simulation profits would be published after the final simulation should have provided a good incentive for participants to aim at high payoffs.

We observe that the average contribution to the collective investment increases from one simulation to the next. In all three simulations we observe, however, the same pattern. Initial contributions are highest. They decrease during the first few rounds, to remain then almost constant, until they decrease drastically in the final rounds. The average contributions in the final round almost coincide with the dominant strategy solution.

The analysis of the strategies submitted for the final simulation reveals several typical properties, each characterizing a majority of strategies It is not necessarily the case, however, that each strategy has all of these properties. Strategies have a 3-phase structure. In an initial phase they contribute their entire endowment to the collective investment. In an end phase, which lasts 1 to 6 rounds, they play the dominant strategy contributing 7 tokens to the collective alternative, whatever the history of the game so far. The behavior in the intermediate phase can be described by reciprocity. The contribution of strategy i to the collective investment in round t, $y_{i,t}$, is determined as

$$y_{i,t} = \text{ROUND}(\sum_{j \neq i} y_{j,t-1}) + \alpha_i \qquad \text{with } \alpha_i \in \{-1, 0, 1, 2, 3\}.$$

A strategy's contribution to the collective investment is based on the average contribution of the other players in the previous round. Since decisions can be made as integers only, the observed averages have to be rounded to the nearest integer. Furthermore, we observe that an integer α_i is added, which is constant over time but different for each strategy i. A positive α_i is chosen by more strategies than a negative one. This means that strategies following this rule rather contribute a little more than less than the observed average contribution of the other players in the previous round. Furthermore, strategies pay attention never to contribute fewer than 7 tokens to the collective investment. Similarly to other strategy experiments (in particular, Selten, Mitzkewitz and Uhlich, 1997), we observe that a strategy with more typical properties tends to be more successful than a strategy with less typical properties.

We have to be aware of the fact that strategic behavior cannot be supposed to fully reflect spontaneous behavior of subjects. In the strategy experiment, subjects are forced to analyze the game, at least to some extent, and to construct decision rules for the entire game. When subjects interact spontaneously, they neither have the time nor consider it their task to analyze the game in detail. Decision rules may be made up from one round to the next. Thus, spontaneous behavior is likely to be more erratic and driven by feelings of sympathy or dislike toward the others than strategically planned behavior. We consider the strategy experiment a complement, not a substitute for, spontaneous game-playing experiments. Obviously, in the public goods situation, reciprocity plays a role in both strategic and spontaneous experiments. The typical strategic behavior is compatible with the model of conditional cooperation presented in Keser and van Winden (*forthcoming*). The strategy experiment further reveals that reciprocity is considered as an instrument to lead others to cooperation. The own willingness to cooperate is signaled in the first round by maximal contribution to the collective investment. This result is in keeping with those of earlier strategy experiments on the prisoner's dilemma and oligopolies (Axelrod, 1984; Selten, Mitzkewitz and Uhlich, 1997; Keser, 1992; see also Selten 1998).

4. Punishment

In the previous section we have seen evidence for reciprocity in public goods experiments. Reciprocity shows in an orientation of a subject's contribution level at the observed contribution of others. It is used as an instrument to achieve cooperation with others. Reciprocity of this kind can show in other aspects of behavior which are not captured by the typical public goods model. Reciprocity may, for example, be expressed by punishing others even if this incurs costs to the one who punishes. In other words, also punishment may be considered an instrument to achieve cooperation with others. Ostrom, Gardner and Walker (1992) allow for costly punishment in a common pool resource experiment (see Section 6 below for a description of the common pool resource game). They observe that subjects make use of this opportunity which increases the overall level of cooperation. Fehr and Gächter (1999) allow for costly punishment in a public goods experiment. Their baseline public goods game without punishment has the parameters n = 4, e = 20, T = 10, and the profit function

$$\Pi_i\,(x_i,\ \sum_{j=1}^{4} y_j\,) = x_i + 0.4\sum_{j=1}^{4} y_j$$

In their public goods game with punishment, there is a second decision stage, after the contribution decision in each period. Each player is informed about the individual contributions to the public good and, then, has the opportunity to punish each of the other group members. Player j can punish group member i by assigning him punishment points, p^i_j. For each punishment point assigned to i, the first stage payoff of player i is reduced by 10 percent. The first stage payoff of player i is never reduced below zero. Thus, the number of effective punishment points imposed on player i is given by $P^i = \min(\sum_{j \neq i} p_j^i, 10)$. Player i's costs for punishing other players are given by $\sum_{j \neq i} c(p_i^j)$, where $c(p^j_i)$ is strictly increasing in p^j_i as presented in Table 2. The profit function of player i in the punishment model is

$$\Pi_i (.) = (x_i + 0.4 \sum_{j=1}^{4} y_j)\, [1 - (1/10)P^i] - \sum_{j \neq i} c(p_i^j)$$

The game theoretical solution prescribes in both games zero contribution to the collective investment. In the punishment game, punishment should never occur.

Table 2: Punishment levels and associated costs for player *i* punishing player *j*

punishment points p^j_i	0	1	2	3	4	5	6	7	8	9	10
costs of punishment $c(p^j_i)$	0	1	2	4	6	9	12	16	20	25	30

The experiments were organized in a computerized way at the University of Zürich. The authors examined both a partners situation where subjects stay in the same group during the 10 rounds and a strangers situation where subjects are randomly re-matched in each round. 10 groups of 4 subjects were in the partners situation and 3 populations of 24 subjects were in the strangers situation. In each session, subjects played first 10 rounds of one game (baseline or with punishment) and then, without having been informed about that before, 10 rounds of the other game (with punishment or baseline). In the baseline game subjects are informed about the total contribution of the group to the collective investment; in the punishment treatment subjects are informed about all individual contributions to the collective investment in the group and about the aggregate punishments imposed on them by the other group members.

In the experiments we observe in both the partners and the strangers situation that the existence of punishment opportunities causes a large rise in the average contribution level. In the partners (strangers) situation the contribution level increases from 35.5 (18.5) percent in the baseline game to 85 (57) percent in the punishment game. In the punishment game, subjects can "force selfish subjects to adjust contributions towards those levels that they consider as appropriate." (Fehr and Gächter, 1999, page 26) This is typically the contribution level of the others group members. We observe that a subject's negative deviation from the average contribution is strongly punished. The more his contribution falls below the average contribution of the others group members the more heavily he is punished.

5. Games with a flexible interaction structure

In the literature on the public provision of public goods, Tiebout (1956) challenged in a path-breaking article the conjecture by Musgrave (1939) and Samuelson (1954) that public goods cannot be allocated efficiently. He considers a world of local public goods to demonstrate that public goods might be efficiently allocated if agents are fully mobile and can move to those communities that best satisfy their preferences. In Ehrhart and Keser (1999, *in preparation*) we present experiments to examine the private provision of public goods in a kind of Tiebout world, in which each agent belongs to a community but has the opportunity to migrate to another community or create a new one. In our experiments, where subjects may make voluntary contributions to the funding of a public good within their community, we observe that agents frequently migrate to other communities, although mobility is costly. The observed contribution level is significantly above the theoretical prediction and, under certain conditions, closer to the socially efficient level than the observed contribution level in experiments without mobility.

These experiments allow us to obtain a better understanding of individual decision making than in public goods experiments without mobility. We observe that the more cooperative subjects are continually on the run from the less cooperative ones. However, the less cooperative ones keep following them around. Both free-riding and cooperation appear to be active principles, in the sense that free-riders seek to take advantage of the contributions of others and that cooperators try to form groups with other cooperators.

The experiments are based on a typical public goods game with the parameters $n \leq 9$, $e = 10$, and the linear profit function

$$\Pi_i(x_i, \sum_{j=1}^{n} y_j) = x_i + k(n) \sum_{j=1}^{n} y_j$$

where $k(n)$, the return per token in the collective investment, depends on n as presented in Table 3. Note that for $n > 1$, the constraints $nk(n) > 1 > k(n)$ are satisfied.

Table 3: The return per token in the collective investment, *k*(*n*), depending on the group size *n*

n	1	2	3	4	5	6	7	8	9
k(n)	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.33

Our experiments involve a dynamic game with a population of nine players. Each player in this population participates in a sequence of 30 rounds. In the first round, the 9 players are randomly assigned to three separate groups of three players each to play once the public good game with

$n = 3$. From the second round on, each round is divided into two stages. In the first stage, each player decides whether he wants to stay with his group, switch to one of the other groups that existed in the previous round, or create a new group. Switching to another group or creating a new group incurs costs of 5 to the player. In the second stage, each player decides, in the baseline public goods game within his new group of n players, on the allocation of his token endowment between the private and the collective investment.[7] Each player has the following information: in the beginning of the first stage of each round, when he makes his group adherence decision, he knows the size, the total and average group contribution to the collective investment, and the per capita return from the collective investment of each group in each of the prior rounds in which it existed. In the beginning of the second stage of each round, before making his allocation decision, he is informed about the size n of his new group.

In the subgame perfect equilibrium solution of this game, each player allocates, in each round, all of his tokens to his private investment. No player ever changes his group because in doing so he would only incur costs. For the entire population it is optimal, however, if from the second round on they form one group of nine players and if in each round each player contributes all of his tokens to the collective investment.

The experiment was organized in a computerized way with 90 students at the University of Karlsruhe. Thus, we observed 10 independent populations. They contribute on average 52 percent of their endowment to the collective investment; the average group size is 4.6. We observe on average 41 group changes per population.

A fair amount of movement takes place in the experiment. There is a continual growing and splitting of groups. Groups with a relatively high contribution level tend to grow but, once they are growing, contributions decrease and the groups begin to split. New groups arise and the dynamics goes on. We can show that this dynamics is due to the more cooperative subjects being on the run from the less cooperative ones who follow them around.

In Ehrhart and Keser (*in preparation*) we continue this research to examine whether the opportunity for migration has a positive effect on the level of voluntary contributions. We compare behavior in this game with *free mobility* to subjects' behavior in a game *without mobility* and in another game with *limited mobility*.

In the game without mobility, subjects play the baseline public goods game during 30 rounds in the same group of 5 players.[8] We observe that the average contribution of 49 percent of the endowment is below the average contribution in the game with free mobility. The difference, however, is small and statistically not significant (Mann-Whitney U test, 5 percent significance level).

[7] If in the first stage of a round a player has created a new group, he forms a 1-player group during the second stage of the current round.

[8] We have chosen this group size as in the experiments with (free and limited) mobility we observe an average group size of about 5.

The game with limited mobility is similar to the game with free mobility but, from the second round on, each round is divided into *three* stages. In the first stage, players decide by a majority vote whether or not their group should be closed against entry of other players in the current round. In the case of group closure each group member, independently of his individual vote, has to pay costs of 5. In the second stage, each player makes his group choice under the restriction that a closed group cannot be joined. In the third stage, each player decides on the allocation of his token endowment between the private and the collective investment.

We observe an average contribution of 64 percent of the endowment, an average group size of 4.9, and an average of 27 group changes and 7 group closures per population. The contribution level is significantly higher than in the game without mobility and significantly higher than in the game with free mobility (Mann-Whitney U tests, both 1 percent significance level). We conclude that the opportunity to close one's group significantly increases the contribution level. Subjects make use of the opportunity for group closure although it is costly.[9] Another interesting observation is that if a group is closed, the contribution level in that group tends to shrink. The contribution level outside this group, however, tends to increase.

6. Common pool resource situations

A common pool resource (CPR) is a resource in which yield is subtractable and exclusion from appropriation is difficult. Examples of CPRs include grazing commons, high sea fisheries, and irrigation systems. Similar to the public goods situation, in a CPR situation the pursuit of self interest by individuals leads to a collectively undesirable over-exploitation—the tragedy of the commons (Hardin, 1968). In Keser and Gardner (1999) we present an experiment based on the strategy method to examine behavior in a CPR situations. The game is modeled, following Ostrom, Gardner and Walker (1994), as a twenty-fold repetition of a symmetric 8-player game (n = 8). Each player i is endowed with e = 25 tokens, which can be allocated to a safe investment, x_i, or to a CPR, y_i (with $x_i + y_i = 25$). The safe investment yields him a payoff of $r = 5$ per token. The payoff to each player i from investment in the CPR depends both on his own investment, y_i, and on the total investment, $\sum_{j=1}^{8} y_j$, in the CPR. The group payoff to the total investment in the CPR is given by the production function

$$F(\sum_{j=1}^{8} y_j) = 23\sum_{j=1}^{8} y_j - 0.125(\sum_{j=1}^{8} y_j)^2$$

[9] This result is similar to the one by Fehr and Gächter (1999) who show that the costly opportunity to punish each of the other players for no or too small contributions to the collective investment is used by subjects and increases the average contribution.

F is a concave function which implies that at the optimal level of CPR investment, the players invest some but not all of their tokens in the CPR. Each player receives a fraction of the group payoff to the total investment in the CPR proportional to y_i. Thus, the profit function of player i is given by

$$\Pi_i \left(x_i, y_i, \sum_{j=1}^{8} y_j\right) = 5x_i + \left(y_i / \sum_{j=1}^{8} y_j\right) F\left(\sum_{j=1}^{8} y_j\right)$$

In the symmetric subgame perfect equilibrium of the 20-fold repetition of this game, each player invests in each round 16 tokens in the CPR. In the symmetric group optimum, however, each player invests 9 tokens in the CPR, while economic rents are completely dissipated if each player invests 18 token in the CPR.

We observe that although the equilibrium solution organizes the data at the aggregate level (group investment generally lies between the equilibrium prediction and the point of complete rent dissipation), subjects don't behave in accordance with that equilibrium. However, in contrast to the strategy experiment on voluntary contributions to a public good (Keser, 1999) and strategy experiments on oligopolies (Selten, Mitzkewitz and Uhlich, 1996; Keser 1992) we observe no active attempt to achieve a cooperative goal in the CPR situation. We know from the subjects' commentaries that it is not clear to them at which appropriation level cooperation should take place.[10] The relatively large number of 8 players makes the analysis of the game rather complex.

Note that we have experimental evidence that in oligopoly situations (with 2 or 3 players), which are strategically equivalent to the common pool resource situation, symmetry makes it easier for subjects to find a cooperative point. Therefore, we observe more cooperative outcomes in symmetric than in asymmetric oligopolies (Mason, Phillips and Nowell, 1992; Keser, *forthcoming*). In the CPR situation, the subjects' difficulty in identifying a cooperative goal explains the lack of cooperative strategies.

We may conclude that in situations where the pursuit of self interest leads to collectively undesirable outcomes (public goods, common pool resources, oligopolies) cooperative outcomes may occur without government intervention. It is, however, important that the collective interest and the cooperative goal are obvious.

7. Conclusion

Voluntary contributions beyond the game-theoretic prediction are a relatively robust phenomenon. The typical behavior of subjects can be characterized by reciprocity, or, conditional cooperation. Conditionally cooperative subjects seem to use reciprocity as an instrument to attain a cooperative outcome in the interaction with others. However, we also observe free-riders who make no voluntary contributions to public goods and, where possible, actively seek to take advantage of contributions made by others. The coexistence of conditionally cooperative subjects and free-riders in a population can explain the phenomenon of decreasing voluntary contributions. The subjects' opportunity to punish individual others or to migrate to other communities may increase the average level of voluntary contributions to public goods.

We conclude that the prediction of economic theory regarding the private provision of public goods is too pessimistic. Based on the theoretical prediction, the role of the government is often justified by the necessity to provide public goods. This justification seems to have lost some of its grounds. We probably need further experiments to explore in how far financing of public goods by lump-sum taxes can improve efficiency relative to the provision of public goods by voluntary contributions. A first step in this direction has been made by Andreoni (1993) and Chan, Godby, Mestelman and Muller (1998) who examine in experiments to what extent lump-sum taxes for the provision of public goods crowd out voluntary contributions.

[10] Ostrom, Gardner and Walker (1994) show that this can be solved, for example, by communication among subjects.

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Comment on: "Cooperation in Public Goods Experiments"

Claude Montmarquette
Université de Montréal and CIRANO

In this short but elegant paper, Keser discusses the question of public goods in the context of experimental economics. While organized as a survey, Keser mainly focuses on her own contributions to this topic. She and her co-authors offer stimulating insights to all concerned with the role of government in the economy and the problem of voluntary contributions to public goods.

The typical public goods experiment is a straightforward exercise. The Nash equilibrium is zero contribution to the public goods. Investing all its endowment on the public goods is the group optimum. The distinctive result in those experiments is a voluntary over-contribution relatively to the Nash equilibrium, but an under-contribution with respect to the optimum solution. Keser (1996) has hit a real breakthrough in this literature by presenting an experiment where a dominant strategy is for each player to contribute not all his or her endowment to the private goods. This approach eliminates the subjects' error making to explain the traditional results. Although she observes statistically significant over-contributions by the participants with respect to the Nash equilibrium, the over-contributions appear less important than what was found in the previous literature. Her model opens the way to understand individual human behavior in a more realistic setting, as corner equilibrium can indeed be questionable when spending is limited to only two goods. To be useful for policy issues, experimental economics needs to explain real and complex situations and not only simple make-up laboratory situations. In an experiment currently underway at CIRANO, Keser is looking at a situation where the group optimum is a partial contribution to public goods. This is an important experiment. The assumption that the group optimum is for all players to invest their whole endowment to the public goods is unrealistic since, if realized, the economy should be producing only pure public goods.

The definition of a pure public good characterized by its non-rivalry in consumption and its non-exclusion from consumption implies for the social optimum that all people in the world should voluntarily contribute to its production. Each individual is able to consume those goods while sharing the costs of production with the others. Commitments to find a cure to a very contagious disease will be a genuine example of pure public goods. A global communication system can also be considered an international public good. At a national level, national defense, and a clean environment are the usual examples. Public goods can also be produced locally. The illumination of Berlin at night can be enjoyed by all people leaving in Berlin, but are of little interest for the habitants of Bonn. In Ehrhart and Keser (1999), the production of local public goods is examined with an experiment in which each agent belongs to a community but has the opportunity to migrate to another community or create a new one. In this kind of Tiebout world, the authors found "that free riders seek to take advantage of the contributions of others and that cooperators try to form groups with other cooperators". This study illuminates many debates around the world directly related to this context. In the U.S, and certainly elsewhere, a very hot topic is the debate among the pros and cons for a centralized or a decentralized educational system and with respect to the private/public division of responsibility for education. In Europe and in Canada, a major question is federalism or decentralized government, while in Asian and Latin American countries, the discussion focuses on whose in and whose out as free trade partners.

Contrary to a widely held view, Isaac et al (1994) found that larger group size provides public goods more efficiently than smaller group size. This question is revisited in Keser and van Winden (forthcoming) with public goods experiments using partners and strangers. In the experiments realized with partners, players interact in the same group during the entire game. With strangers, groups are randomly formed in each repetition. Thus, indirectly, the group of strangers is larger than the group of partners. Keser and van Winden's results indicate greater voluntary contributions from the partners groups than among strangers. In a partner's situation, it seems more useful to signal a willingness to cooperate. Thus, this experiment predicts that despite a smaller differential in the return between the public and the private goods investments facing them (in the public choice median voter model this corresponds to a larger per unit cost of production of the public goods), individuals in small communities are more inclined to allocate a greater percentage of their income to the public goods than those leaving in large communities do. Put it differently, people in small communities are more cooperative.

A particularly original contribution by Keser is her study of strategic behavior with 50 scientists from 13 countries playing the public goods game. She argues that conditional cooperation is strongly supported to explain how subjects behave and that conditional reciprocity is a strong instrument to achieve cooperation. This has two major implications. First, it might explain, why so few international public goods exist. Either for political, historical or economic reasons, conditional cooperation is not easily achieved at the world level. More generally, the rule is "defection reciprocated with defection" as we observe perennial discussions and difficulties of financing international institutions. Second, if conditional cooperation can be used to achieve cooperation, this suggests some policy designs. Mobility among groups was mentioned as a possibility to enhance conditional cooperation. Perhaps key information on contributions, identification of the players, allowing discussions among participants or a structure of punishment for those who contribute below the group average contribution (discussed in the section 4 of the survey) merit consideration and exploration.

In her survey, Keser discusses also the question of uncertain group payoffs and mentions taxes. It would have been useful to link some of these parts with other sections that have been more developed. For example, how the level of trust or the uncertainty of other contributions might play in the strategy of conditional contribution. To the extent that the initial period decision lacks information about the other contributions and might be influential to the dynamics of the game, this could be an interesting question. The role of taxes in the migration study is also a subject worth considering.

A small regret concerns her too short discussion of the notion of reciprocity without reference to preferences using Alxerod's definition. Becker (1962) has long since shown that the law of demand can be derived without a utility function. Experimental works by Evans (1997), Gode and Sunder (1993) suggest that efficiency are derived from the structure of the market rather than motivation, intelligence and learning ability of human economic agents. If constraints and market structures appear more important than preferences why is the trend in experimental economics to add elements to the utility function such as altruism, fairness or distaste for inequality? A more critical discussion of this point in her survey would have been helpful for future work.

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(Omitted references are found in Keser)

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