Non-Cooperative Behavior in a Public Goods Experiment with Interior Solution

Marc Willinger[a], **Anthony Ziegelmeyer**[b]

[a]Institut Universitaire de France, BETA-*Theme* — Université Louis Pasteur, 61 avenue de la Forêt Noire, F–67085 Strasbourg Cedex.

[b]BETA-*Theme* — Université Louis Pasteur, 61 avenue de la Forêt Noire, F–67085 Strasbourg Cedex.

September 27, 1999

Abstract

We designed an experiment on voluntary contributions to a public good with interior solution. The treatment variable is the equilibrium level of contribution. We observe that the average overcontribution rate (cooperation) is affected by the equilibrium level of contribution. Overcontribution is statistically significant only at the lower level of equilibrium contribution but not at the higher levels. We discuss several possible explanations, and suggest that behavioral heterogeneity might account for the observed pattern of overcontribution. Simulation results based on a simple model of heterogeneous interacting agents confirm our intuition.

Résumé

Dans cet article, nous présentons, dans un premier temps, les résultats d'une expérience relative aux mécanismes de contribution volontaire à un bien public. Notre expérience repose sur un jeu de base, répété 25 fois, qui se caractérise par une stratégie dominante d'investissement partiel dans le bien public. Notre variable de traitement est le niveau de contribution d'équilibre. Plus précisèment, nous considérons quatre traitements différents dont les niveaux de contribution d'équilibre sont respectivement 7, 10, 13 et 17 jetons; chaque sujet ayant une dotation initiale de 20 jetons. Nous constatons alors que le taux de sur-contribution moyen observé est influencé par le niveau de contribution d'équilibre. En effet, les sujets ont une sur-contribution moyenne significativement différente de zéro uniquement pour le traitement ayant le plus faible niveau de contribution d'équilibre. Dans un deuxième temps et afin d'expliquer nos données expérimentales nous présentons un modèle d'apprentissage individuel avec hétérogénéité des agents. Nous simulons notre modèle en faisant varier la propension à l'apprentissage des agents, et nous obtenons des dynamiques de contribution moyenne proches de celles observées au sein du laboratoire.

Keywords: experimental economics, public goods, learning

JEL Classification: C72, C92, H41

1 Introduction

Experiments on public goods games have shown that subjects tend to contribute a significant amount of their endowment, even when the dominant strategy is to contribute nothing. Cooperation in public goods games is robust to various treatment variables. Even if some variables (repetition, low marginal values of the public good) reduce sharply the contribution level, cooperation is not completely eliminated (see Ledyard (1995) for a survey). Several explanations have been suggested to account for this result.

Overcontribution may be due to decision errors (see Andreoni (1995), Palfrey and Prisbey (1997)). If the single-shot dominant strategy is to contribute zero to the public good, any error will lead to a positive contribution, as long as negative contributions are not allowed. A simple test of the error hypothesis can be done if the single-shot dominant strategy is to contribute something to the public good. Keser (1996), for example, showed that even with an interior solution, there is a significant rate of overcontribution. A second argument was raised by Kreps, Milgrom, Roberts, and Wilson (1982) to explain rational cooperation in a finitely repeated Prisoner's Dilemma under incomplete information. Suppose, that both players believe that there is a small chance that their opponent adopts a tit-for-tat strategy. Then it could be in each player's best interest to pretend, at least for some time, to be of the reciprocal altruistic type in order to build a reputation for cooperation, until the game eventually unravels to mutual defection. Another reason for overcontributing is the kindness/reciprocity motive. Players are kind to the other players because they expect that other players will react by being kind also. Since all the players are better off if they all contribute their total endowment to the public good, there is a strong incentive for being kind to induce reciprocity. Finally, subjects may be altruistic and overcontribute to increase other players' welfare (Dawes, McTavish, and Shaklee (1977), Marwell and Ames (1979), and Andreoni (1990)).

In this paper we argue that none of these explanations is fully satisfactory. Our argument is based on new experimental data on contributions with an *interior solution*. The public goods game is a 25-fold repetition of a constituent game which has a *unique dominant strategy equilibrium* corresponding to partial contribution. We compare the data for four equilibrium solutions: "low" equilibrium contribution (L), "middle" equilibrium contribution (M), "high" equilibrium contribution (H) and "very high" equilibrium contribution (VH). Our results confirm Isaac and Walker's (1998) observation that moving the equilibrium level of contribution closer to the Pareto optimum, leads to a decrease in average overcontribution.[1] However, in contrast to the results of Isaac and Walker (1998), we did not find, for high levels of equilibrium contribution, that subjects on average tend to undercontribute. We shall argue that this contrast could be due to the fact that their design implies multiple individual equilibria, each depending on the level of others' contributions, instead of a unique Nash equilibrium in dominant strategies as in our design.

We show that our data can be explained by the *coexistence* of two types of players: *strategic players* and *reciprocal players*. We designed an individual learning model which allows these two types of behaviors to interact over 25 periods like in our experimental data. In the model, the level of overcontribution in each period depends both on the interaction of the two types of players and on the initial level of overcontribution, which we set equal to the levels observed in the experiment. Our simulation results agree in many cases with the data of our experiment. We suggest that combining *heterogeneity of behaviors* and *learning* is appropriate for modeling the dynamics of the average rate of overcontribution.

The paper is organized as follows. Section 2 presents the experimental design and procedures. In section 3 we present the theoretical predictions of the constituent games of our experiment. The results are presented in section 4. Section 5 presents the behavioral assumptions of our model. In section 6 we summarize the main results of our simulations. Section 7 concludes the paper.

2 Experimental Design

We implement an experimental design in order to study the impact of the interior equilibrium level of contribution on the average rate of overcontribution. Interior solutions for the public goods game can be obtained by defining a non-linear earnings function, either in private and/or public consumption. In the first case, one obtains a dominant-strategy specification while in the second case we have a unique equilibrium for *aggregate* contributions (for a survey on the evidence from interior-Nash public goods experiments see Laury and Holt (forthcoming)). As in Keser (1996), our design is based on a *quadratic payoff function for the private good.*

2.1 The four treatments

Each participant was randomly assigned to a group of four people (including himself) for the 25 periods of the experiment. At the beginning of each period, each subject was endowed with 20 tokens, which he had to allocate between a private activity and a public activity.[2] The constituent game has a dominant strategy equilibrium where each player contributes a positive number of tokens to the public activity, noted c^*, which is also the level of contribution predicted by the unique subgame-perfect equilibrium for the 25-fold repetition of the constituent game.

Let x_i be the number of tokens invested by player i ($i = 1, 2, 3, 4$) in his private activity and $c_i = 20 - x_i$ the number of tokens invested in the public activity. The payoff of player i is given by:

$$\prod_i \left(x_i, \sum_{j=1}^{4} c_j \right) = 41x_i - {x_i}^2 + \theta \sum_{j=1}^{4} c_j \tag{1}$$

where $\theta \in \mathbb{N}$ is the marginal revenue from investing in the public good. $41x_i - {x_i}^2$ is the payoff of the private activity and $\theta \sum_{j=1}^{4} c_j$ is the payoff of the public activity. Each player i chooses the number of tokens to invest in the public good so as to maximize $\prod_i \left(x_i, \sum_{j=1}^{4} c_j \right)$ subject to the budget constraint $x_i + c_i = 20$, given other players' strategies. The payoff function of player i can be rewritten as:

$$\prod_i \left(x_i, \sum_{j \neq i} c_j \right) = (41 - \theta)x_i - {x_i}^2 + 20\theta + \theta \sum_{j \neq i} c_j \tag{2}$$

where $\theta \sum_{j \neq i} c_j$ is the (positive) externality generated by the other players on the payoff of player i. The level of the externality depends on the value of θ. There is a unique Nash equilibrium where each player invests $x^*(\theta) = (41 - \theta)/2$ in the private investment and contributes $c^*(\theta) = (\theta - 1)/2$ to the public good. Moreover the repeated game has a unique subgame-perfect equilibrium where each player contributes exactly c^* tokens per period to the public activity. The social optimum requires that each member contributes 20 tokens to the public activity.[3]

In our experiment we compare the level of contribution for four different values of $\theta: 15, 21, 27$ and 35. The corresponding equilibrium contributions to the public good are 7, 10, 13 and 17 respectively. Table 1 summarizes the predictions for the four treatments.

Equilibrium condition	**Public good's marginal revenue (θ)**	**Optimal level of contribution (c^*)**
Low (L)	15	7
Middle (M)	21	10
High (H)	27	13
Very High (VH)	35	17

Table 1: Experimental design.

2.2 Practical procedures

The experiment was run on a computer network[4] in Winter 1998 using 64 inexperienced students at the BETA laboratory of experimental economics (LEES) at the University of Strasbourg. The subjects were recruited by phone from a pool of 800 students. They were a mixture of economics (about 20% of the pool) and other majors. Four sessions were organized, with 4 groups of 4 subjects per session. A total of 4 independent observations per treatment was collected. Subjects were randomly assigned to a group of four players, to play a 25-fold repetition of the one-shot game, on a computer terminal, which was physically isolated from other terminals. Communication, other than through the decisions made, was not allowed. The subjects were instructed about the rules of the game and the use of the computer program through written instructions (available upon request), which were read aloud by a research assistant. Group and individual returns from the private and public activity were presented in tabular form to the subjects. A short questionnaire and two practice rounds followed. Subjects earned points that were converted into French Francs (FF) at the end of the session. The number of points accumulated since the beginning of the experiment was on permanent display and each subject had the complete history of the game he or she was involved in available on the computer screen. At the end of a session, each subject was paid privately the total amount he/she had earned during the session. Subjects earned 30 FF show-up fee along with their earnings in the experiment. Table 2 gives the summary of the subjects' payoffs and the conversion rates used in our experiment. Note that with a constant conversion rate, for any given strategy profile such that the sum of the contributions is strictly positive, subjects would earn more money in the high equilibrium condition than in the other treatments. Therefore, we adjusted the conversion rate in order to keep constant the incentives to adopt the equilibrium strategy. Subjects on average earned more money in the low equilibrium condition than in any other of the treatments. This is in accordance with the observed overcontribution rates we analysed in the next section. The actual playing of the 25 repetitions of the one-shot game took less than 1 hour in each treatment. The actual payoffs are quite high relative to such a short time span.

Equilibrium condition	**Maximum payoff**	**Mean payoff**	**Minimum payoff**	**Conversion rate (for 1000 points)**
Low (L)	76	70	62	3
Middle (M)	69	62.5	55	2
High (H)	66	61.5	56	1.5
Very High (VH)	67	64	60	1

Table 2: Summary of the subjects' payoffs (show-up fee not included).

3 Theoretical predictions

At the equilibrium level of contribution $c^* = (\theta - 1)/2$, the marginal return from the private activity is equal to the marginal return from the public activity. Note that $2c_i + 1 = 41 - 2x_i$ is the marginal return from the private activity and θ is the marginal return from the public activity. The marginal per capita return for player i ($MPCR_i$) is defined as the ratio of the marginal return from the public activity to the marginal return from the private activity:

$$MPCR_i = \frac{\theta}{1 + 2c_i} \tag{3}$$

At the equilibrium level of contribution, the $MPCR_i$ is equal to one. If it is smaller than one player i has an incentive to invest more in the private activity and less in the public activity. If it is larger than one, player i has an incentive to invest more in the public activity and less in the private activity. We can therefore use the $MPCR$ as a measure of individual incentives to reallocate tokens from private to the public activity (and vice-versa) when the allocation is sub-optimal. The smaller the $MPCR$, the larger the gain from moving one token from the public to the private activity. Let η_i be the rate of overcontribution of player i:

$$\eta_i = \frac{c_i - c^*(\theta)}{x^*(\theta)} \tag{4}$$

so that the contribution of player i can be written as $c_i = c^*(\theta) + \eta_i x^*(\theta)$ and the $MPCR_i$ can be rewritten:

$$MPCR_i = \frac{\theta}{\theta + \eta_i(41 - \theta)} \tag{5}$$

This relation shows that an increase in the rate of overcontribution does reduce the $MPCR$, i.e. the higher the rate of overcontribution, the weaker the incentive to contribute more to the public good. Note that, if η_i is positive, $\partial MPCR_i/\partial\theta \geq 0$, which means that an increase of the marginal return of the public good (θ), lowers the incentives to reallocate tokens from the public to the private activity. In other words, if subjects acted in a way to keep the $MPCR$ constant at a suboptimal level, then we should observe *larger* rates of overcontribution for *larger* values of θ. The relation between the $MPCR$ and the rate of overcontribution is illustrated in figure 1.

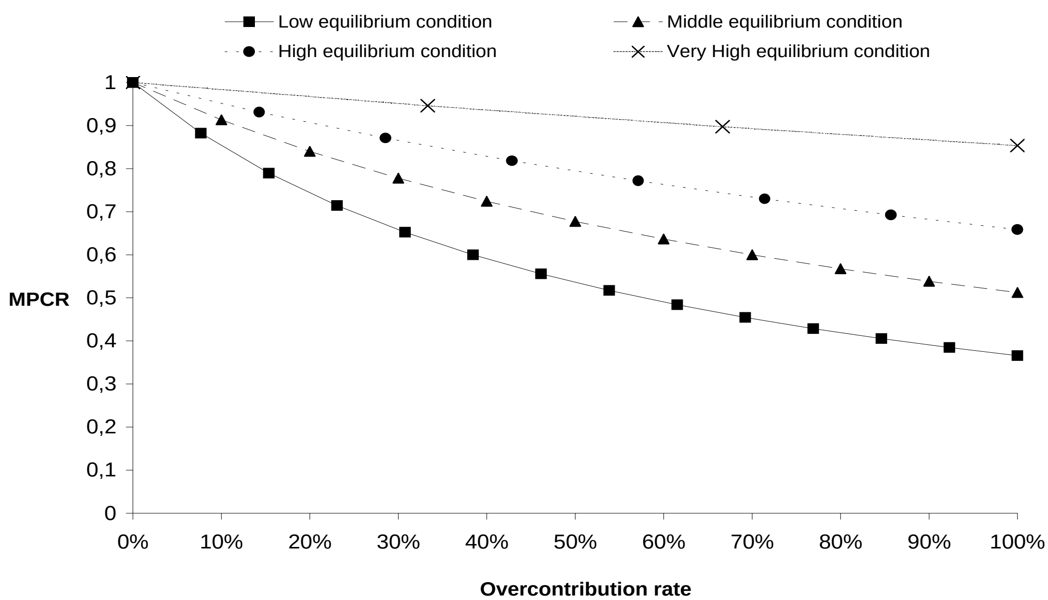


Figure 1: Relation between the $MPCR$ and the overcontribution rate.

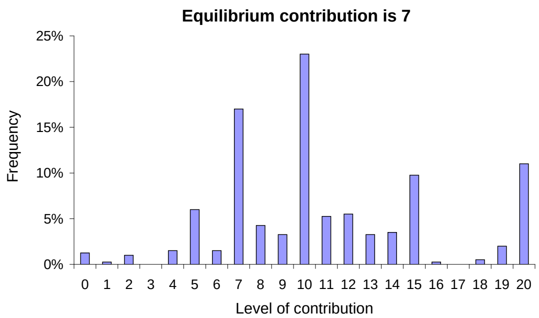
4 Experimental results

Table 3 provides a summary of our experimental data. Column 2 identifies each independent group of subjects in each treatment. The third column of the table presents, for each independent group of subjects, the average contribution to the public good in period 1 and the fourth column presents the average contribution over all 25 repetitions. We present the average overcontribution rate over all 25 repetitions for each group in the fifth column (standard deviations are given in brackets). Finally, the sixth column of table 3 presents the average overcontribution rate over all 25 repetitions and over all the 4 groups in each treatment (standard deviations are given in brackets).

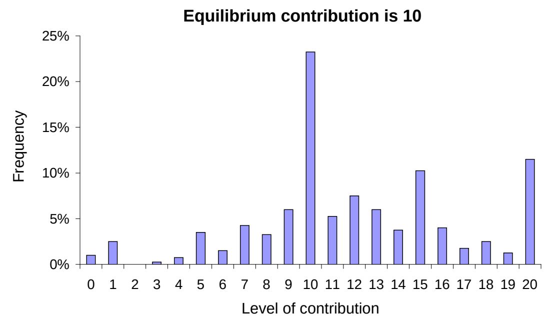
	Group	Average contribution in period 1	Average contribution over all 25 periods	Average overcontribution rate	Mean average overcontribution rate
	L1	8.50	10.80	0.29 (0.31)	
Low (L)	L2	13.25	11.01	0.31 (0.38)	30.13 %
equilibrium	L3	13.50	11.46	0.34 (0.43)	(0.36)
condition	L4	10.75	10.40	0.26 (0.3)	
	M1	12.50	12.88	0.29 (0.45)	
Middle (M)	M2	13.75	11.88	0.19 (0.38)	19.95 %
equilibrium	M3	10	11.75	0.17 (0.57)	(0.46)
condition	M4	12.50	11.47	0.15 (0.43)	
	H1	12.75	12.08	- 0.13 (0.61)	
High (H)	H2	14	13.85	0.12 (0.67)	2.07 %
equilibrium	H3	13.5	13.05	0.01 (0.34)	(0.53)
condition	H4	13.25	13.6	0.09 (0.38)	
	VH1	14.25	16.62	- 0.13 (0.89)	
Very High (VH)	VH2	19.25	18.36	0.45 (0.84)	19.50 %
equilibrium	VH3	16.50	17.79	0.26 (0.76)	(0.85)
condition	VH4	15.25	17.57	0.19 (0.82)	

Table 3: Summary of the data.

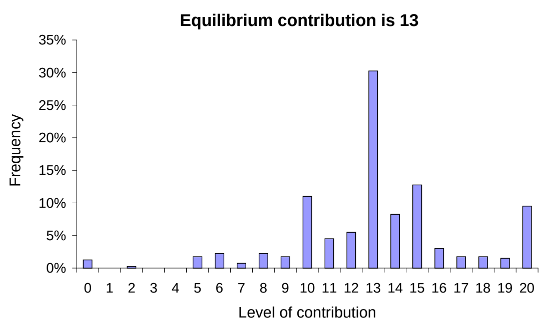
We observe that the average rate of overcontribution is largest for the low equilibrium condition. Applying a χ^2 test, we can reject the null hypothesis of no difference between the average level of contribution and the equilibrium prediction at the 5 percent level ($p = 0.03$). In treatments M, H and VH the average level of contribution is *not* significantly different from the equilibrium prediction at the 5 percent level ($p = 0.64$, $p = 0.99$ and $p = 0.98$ respectively). This result contrasts with previous experiments on public goods games that have induced an interior equilibrium by specifying a declining marginal value for the private good (see Keser (1996), Sefton and Steinberg (1996), and van Dijk, Sonnemans, and van Winden (1997)). Obviously, overcontribution is *not* a systematic outcome when the equilibrium solution is to contribute a positive amount of the initial endowment. There is especially a sharp contrast between treatments L versus H. While the average rate of overcontribution declines by moving from L to M and from M to H, it increases by moving from H to VH. This is partly due to the very high level of contribution of one group (VH2) which started in period 1 at almost full contribution (19.25) and remained at a very high level throughout the 25 periods. Furthermore, any small positive deviation from the equilibrium at $c^* = 17$ has a very strong impact on the rate of overcontribution. Indeed, in the VH treatment, the rate of overcontribution can only take three different values, 1/3, 2/3 and 1, corresponding to levels of contribution 18, 19 and 20 respectively. A unit of deviation above the VH equilibrium increases the rate of overcontribution by 1/3, while the same deviation leads only to an increase of 1/13 at the L equilibrium, 1/10 at the M equilibrium and 1/7 at the H equilibrium. This particularity of the VH treatment is further illustrated by the frequency distributions of the levels of contributions (see figure 2). In the L, M and H treatments we observe more than two peaks. For the VH treatment we only observe peaks at the equilibrium level and at the social optimum (both levels of contribution represent almost 80 % of all contributions), which lead to a higher variance of the rate of overcontribution than for other treatments (see table 3). We used F-tests to compare the variance of individual overcontribution rates in the VH equilibrium treatment to the variances of individual overcontribution rates in the three other treatments. We reject the hypothesis that the variance in the VH equilibrium treatment is the same than in any of the other treatments, at the 5 % level. Overcontribution rates in the VH equilibrium treatment exhibit significantly more variance than in the other treatments.



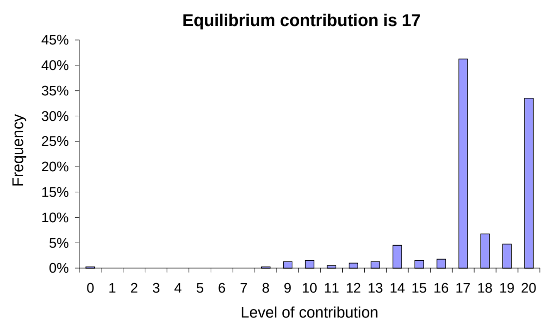
(a) Low equilibrium condition (L)



(b) Middle equilibrium condition (M)



(c) High equilibrium condition (H)



(d) Very High equilibrium condition (VH)

Figure 2: Observed frequencies of contribution.

Figures 3, 4, 5 and 6 show the time paths of the average contribution for the four treatments. The general pattern is a decrease of the rate of overcontribution with the repetition of the game for treatments L, M and H. There is a tendency, in treatments L and M, to approach the equilibrium solution over time. This suggests that more and more subjects played the equilibrium solution as the game was repeated. In the last period of the experiment, for each treatment, the rate of overcontribution does *not* significantly differ from zero. In treatment H the rate of overcontribution moves around the equilibrium, and even ends with a strong undercontribution in the last period. In the case of treatment VH, we observe a slight undercontribution in period 1 followed by an increase and a roughly stable overcontribution throughout the game.

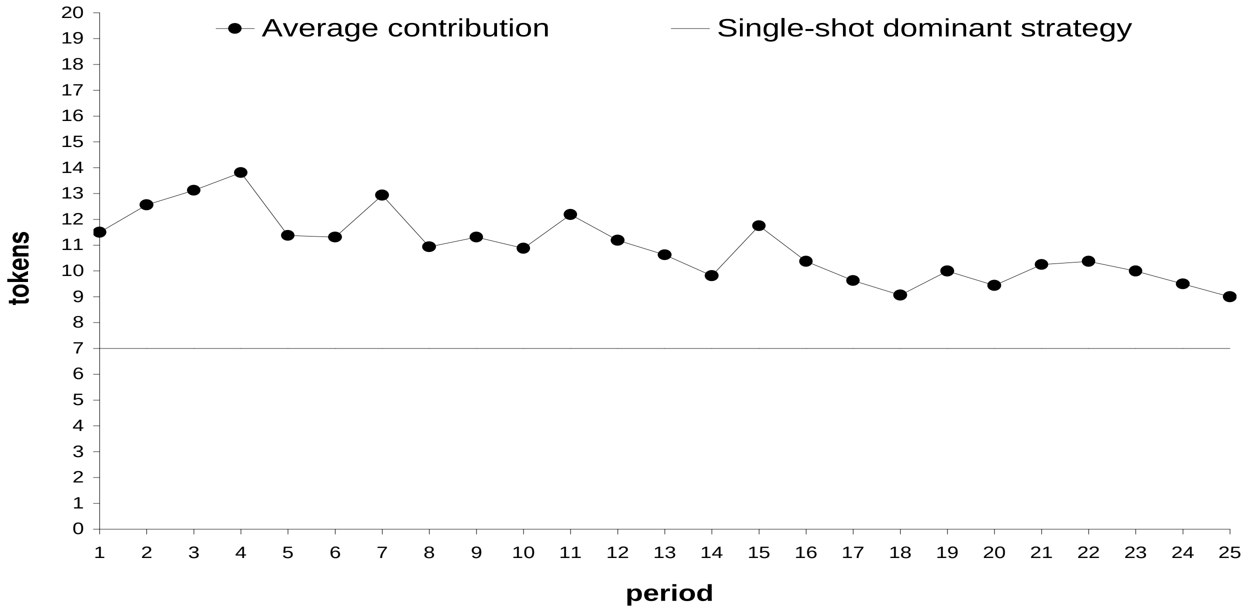


Figure 3: Time path of the average contributions to the public activity in treatment L.

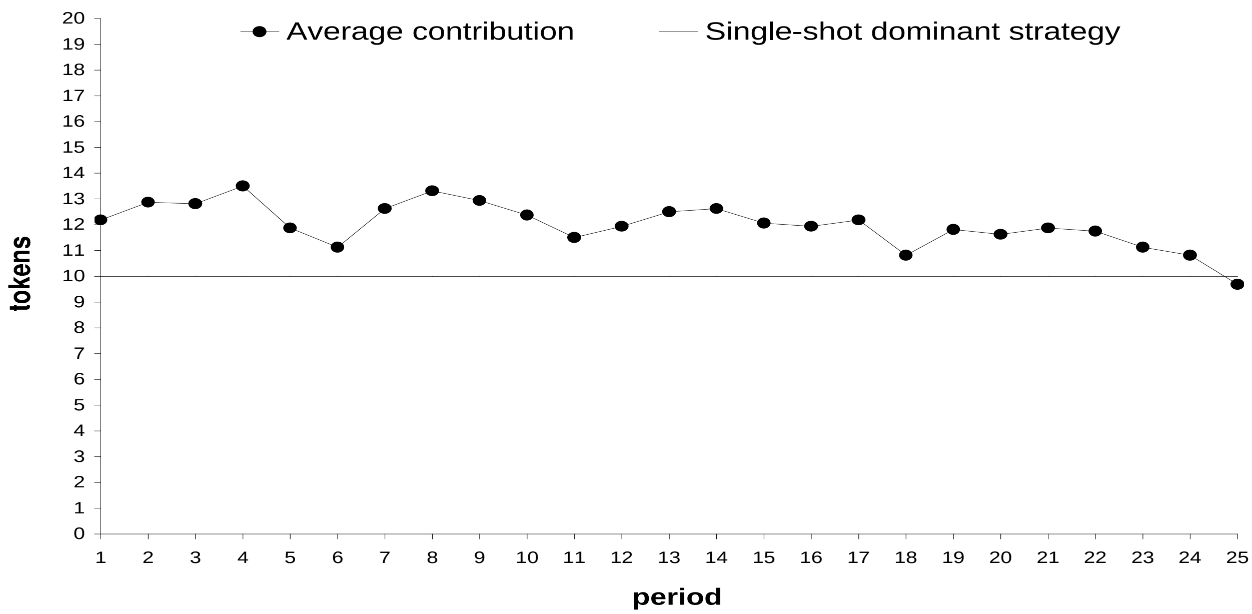


Figure 4: Time path of the average contributions to the public activity in treatment M.

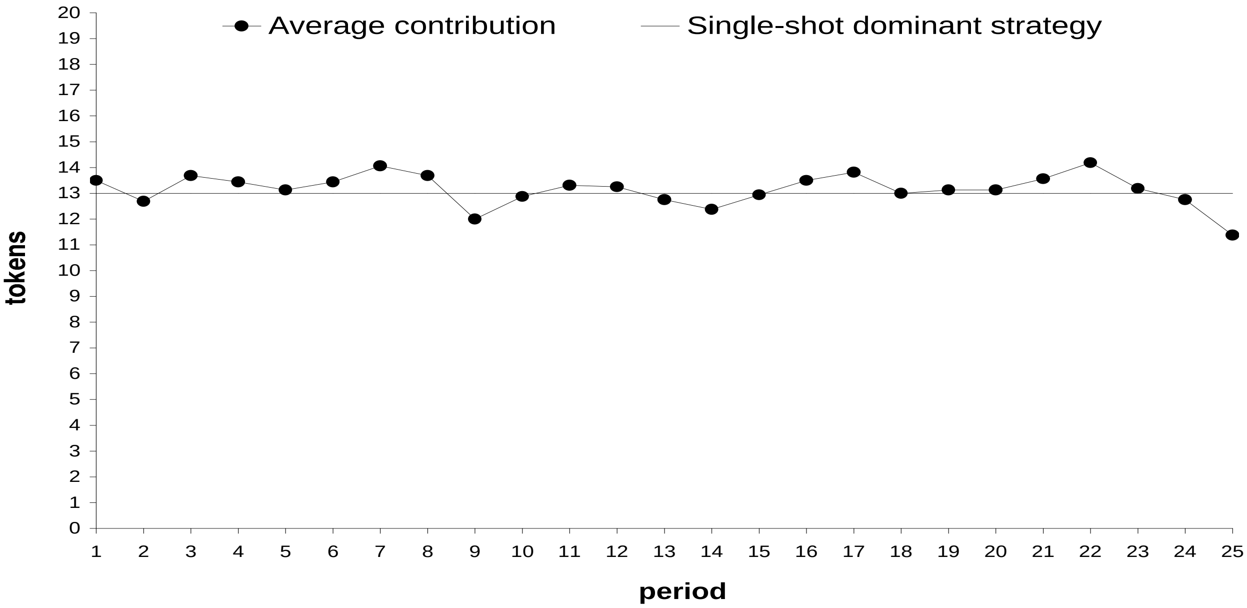


Figure 5: Time path of the average contributions to the public activity in treatment H.

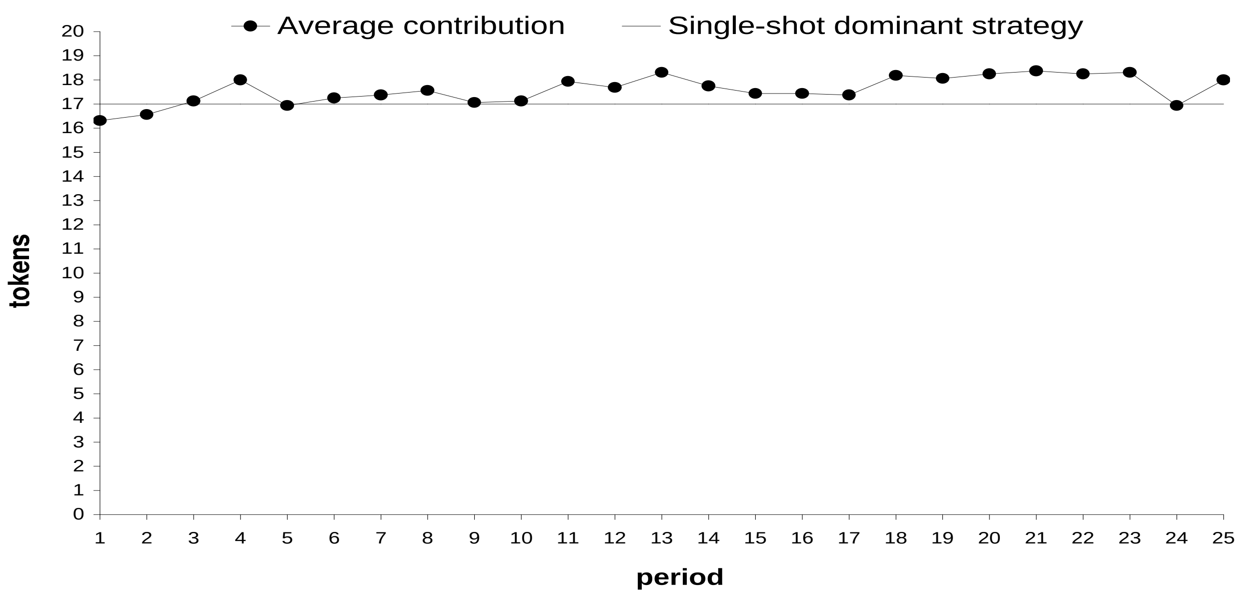


Figure 6: Time path of the average contributions to the public activity in treatment VH.

Contrary to the standard theoretical predictions concerning the $MPCR$, we observe that by moving up the equilibrium level of contribution from L to M and from M to H, the average rate of overcontribution decreases. Figure 7 shows the time paths of the average overcontribution rate for treatments L, M and H. For treatments L and M, we observe that the average rate of overcontribution increases in the four initial periods, followed by an unregular decline for the remaining periods. For the H treatment there is a tendency for the rate of overcontribution to move around the equilibrium level of contribution. Figure 8 shows the time path of the average rate of overcontribution for the VH treatment. We observe a higher variability for this treatment than for the three other treatments. We also observe that the rate of overcontribution curve at the VH equilibrium is not located below the curves that correspond to the other treatments, but intersects each of them at several points (compare figures 7 and 8). This can partly be explained by the higher variance at the VH equilibrium. As we already mentionned, by restricting the set of overcontribution levels –when moving the equilibrium level upwards–, deviations from the equilibrium level of contribution will affect more the variance of the overcontribution rate. A rough correction accounting for this effect is simply to compute the ratio of the average overcontribution rate to the standard deviation. This gives us the following values for the four equilibrium conditions: 0.84 for the L treatment, 0.43 for the M treatment, 0.04 for the H treatment and 0.23 for the VH treatment. According to this correction the overcontribution rate of the very high equilibrium condition is lower than the overcontribution rate of the middle equilibrium condition and closer to the high equilibrium condition's overcontribution rate although higher. Compare to the values of the last column in table 3 this is more in accordance with the expected tendency of decreasing overcontribution rates.

Isaac and Walker (1998) observed significant undercontribution at high levels of equilibrium contribution. The question is therefore whether the curve of the average rate of overcontribution for the VH treatment should lie below the corresponding curve for the H treatment. As we already pointed out in the introduction, Isaac and Walker (1998) have a single-shot Nash equilibrium in total contribution. Their equilibrium is compatible with many combinations of individual levels of contributions in a group. Therefore, subjects probably had more difficulties to coordinate their contributions in their design than in ours, which has a dominant strategy equilibrium for the stage game.

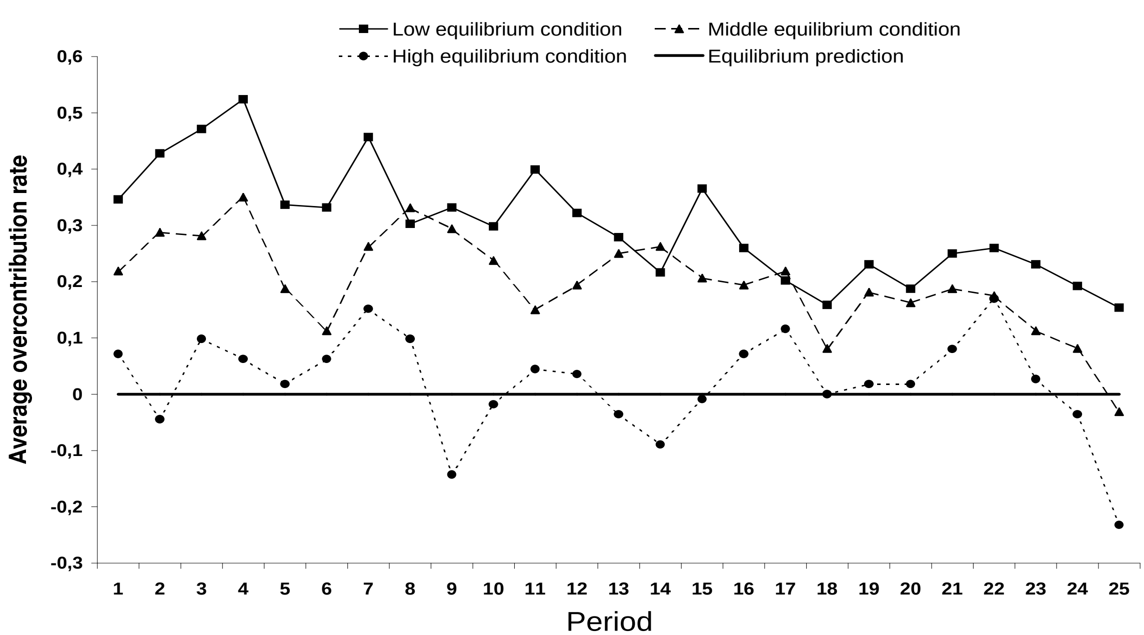


Figure 7: Time paths of the average overcontribution rates of treatments L, M, and H.

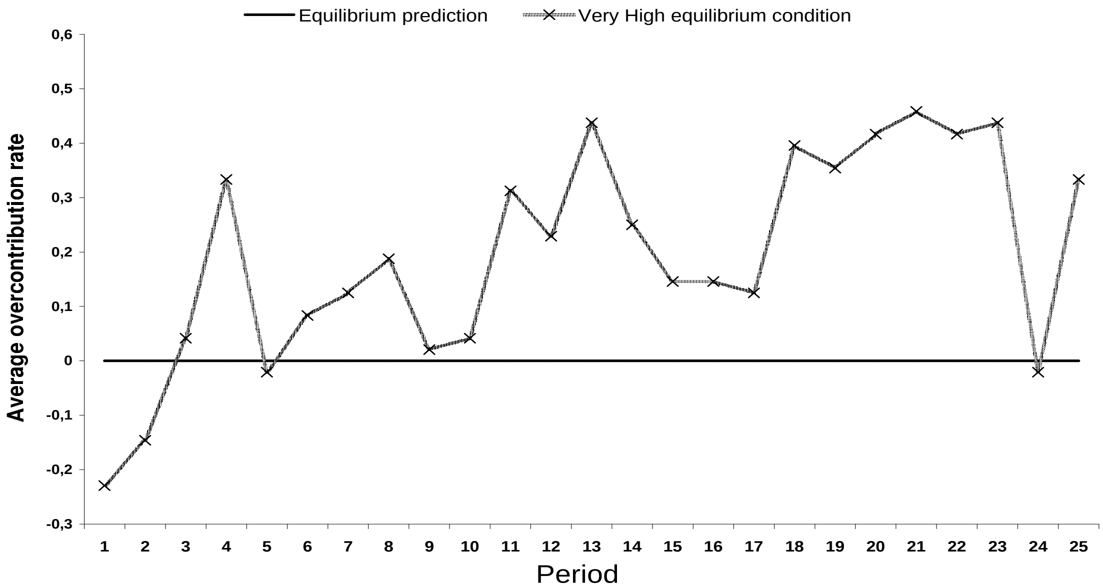


Figure 8: Time path of the average overcontribution rate of treatment VH.

The observed patterns taken together obviously reject the idea that in a public good game the subjects always behave like selfish payoff maximizers, as standard game theory would predict. Other behavioral rules, such as altruism, kindness or reciprocity, do not seem to fit better the data, since the average rate of overcontribution is not significantly different from zero for treatments M, H and VH. Holt and Laury (forthcoming) survey several dynamic models of evolution and adjustment. They conclude that key elements like altruism, error, learning, endogenous preferences, and signaling are certainly present in the laboratory and that a good model will select the most important of these factors and ignore the others. We argue in the next section that the observed pattern is due to the interplay of different types of behaviors. Our model combines *forward-looking behavior* and *backward-looking behavior* in order to explain the evolution of the average rate of overcontribution (for empirical evidence of both forward-looking and backward-looking behavior in a public goods context see e.g. Sonnemans, Schram, and Offerman (1999)).

According to χ^2 tests the initial level of overcontribution differs significantly from one treatment to another. Concerning the low equilibrium condition, we can reject the null hypothesis of no difference between the initial level of contribution and the equilibrium prediction at the 5 percent level ($p = 0.003$). On the contrary, in treatments M, H and VH the initial level of contribution is *not* significantly different from the equilibrium prediction at the 5 percent level ($p = 0.45$, $p = 0.93$ and $p = 0.82$ respectively). This fact may also account for the observed differences in later periods. We also observe that, except for treatment H, there is considerable inter-group variance of the initial level of contribution in each treatment (see column 3 in table 3). These observations must be taken into account in the simulation procedure of our model.

5 A behavioral model with heterogeneous adaptive players

In this section we introduce a learning model in order to explain the observed differences in the average rate of overcontribution with respect to the equilibrium level of contribution. Moreover, this model also explains the observed dynamics and accounts for persistence of overcontribution at low levels of equilibrium contribution.

The fundamental assumption of the model is *coexistence* of two types of behaviors: *strategic behavior* and *reciprocal behavior*. The idea of the model is based on the assumption that strategic players try to manipulate the reciprocal players which are motivated by "gift exchange". The mere existence of reciprocal agents can affect considerably the aggregate outcome of the game. As pointed out by Fehr and Gächter (1998) this is not only due to the fact that reciprocal agents exist, but also because "the existence of reciprocal types changes the behaviour of selfish types". In the public goods environment, the existence of positive reciprocity due to overcontribution, can induce selfish agents to become nicely in order to generate even more cooperation within the population, but in a purely selfish perspective.

There are many possibilities for modelling the interactions between both types of behaviours, which influence each other by way of the average level of contribution. We believe that one of the most important aspects, when interactions are repeated within a group of players, is that strategies of the selfish players are affected in a complex way.[5] For that reason, instead of a deterministic model based on *fixed types*, we designed a model in which agents can "choose" to adopt a given type of behavior. The probability to adopt a given behavior typically depends on the agent's contribution history, the past contributions of the other players, and the time remaining.

In our model we implement *reciprocity* by assuming that a reciprocal player always adjust his current contribution to the observed average level of contribution of his group in the previous period. Therefore, his current contribution depends only on what happened in the previous period, without any expectation about the future contribution of the group. A reciprocal player who observes that the average contribution in the group is larger than his own contribution responds by increasing his contribution. Symmetrically, if he observes that the average contribution of the other players is lower, he responds by a decrease of his own contribution.

The behavior of a strategic player is oriented towards individual payoff maximization, with a *forward-looking strategy*. He is aware that some players in his group adopt a reciprocal behavior. He will therefore try to manipulate them by adopting an "*instigator*" behavior, which is aimed at "encouraging" more contribution from the group. This implies that he overcontributes himself to raise the average rate of contribution above its current level, in order to induce larger contributions from the reciprocal players. Therefore, in some periods, especially in the early periods of the game, strategic players do not adopt their *single-shot dominant strategy*, but tend to overcontribute. Such a deviation from the single-shot dominant strategy is completely opportunistic, since the strategic player expects that the opportunity loss from deviating will be more than compensated by the expected gain due to increased overcontributions in the group in later periods. As time elapses, the incentive to induce cooperation declines, since the expected gain from a one period deviation becomes smaller. We claim that the incentive to induce overcontribution explains sustained cooperation in public goods games. Moreover, the erosion of this incentive explains why we observe a decrease of the level of overcontribution over time.

It is important to realize that our model is not based on the idea that there are different types of players. Rather, it is based on the assumption that a given player can adopt a strategic behavior in a given period and a reciprocal behavior in a later period, and vice-versa. With a population of agents that are of a *fixed type*, each agent adopting the same behavior in each period, cooperation could not survive. Even with a very high proportion of reciprocal types, it is enough to have a single strategic player in the population to bring the average rate of overcontribution down to zero as time elapses. Therefore, a model with fixed types cannot explain the persistence of overcontribution.

One can also argue that persistent cooperation at low levels of equilibrium contribution could also be explained by other kinds of mixtures of behaviors. For example, instead of assuming that strategic players sometimes become *instigators*, one could assume that reciprocal agents sometimes become instigators. This means that with some probability, in the current period a reciprocal player contributes more than the group average of the previous period, and with a complementary probability he contributes exactly that level. By contributing more than the group average, the reciprocal player tries to persuade other players to increase their contribution to come closer to the Pareto optimum. While such a model seems appealing, it would in many cases predict sustained cooperation over long periods of time. But one of the stylized fact that has emerged from the voluntary contributions experiments is the decline in the average rate of overcontribution at low levels of equilibrium contribution. We argue that to allow for a decline requires a different type of signaling behavior, which takes into account deviations from the single-shot dominant strategy.

Our model is an individual learning model. As in our experiment, we assume that each group is composed of 4 players. In a given period, each of them can either adopt a reciprocal behavior, play the single-shot dominant strategy or adopt an instigator behavior. These behaviors are defined as follows. Let c_t^i be player's i contribution to the public good in period $t > 1$, with $c_t^i \in \{0, 1, 2, \ldots, 19, 20\}$. We note $\bar{c}_{t-1}$ the average contribution of the group in period $t-1$. Recall that the single-shot dominant strategy is characterized by contributing c^* to the public good. Thus a strategic player either contributes $c_t^S = c^*$ to the public good or, if he adopts the instigator behavior, contributes $c_t^S \geq c^* + 1$ to the public good. As an instigator, the strategic player either contributes $c_t^S > \bar{c}_{t-1}$ or $c^* + 1 \leq c_t^S \leq \bar{c}_{t-1}$. In the first case, the instigator behavior is aimed at increasing the average contribution in the group, while in the second case it is aimed at preventing a decline in the average contribution. At last, if player i adopts the reciprocal behavior in period $t > 1$ he contributes c_t^R to the public good, which is the closest integer of $\bar{c}_{t-1}$.

Let us now explain by which rules the behaviors are adopted and how they evolve. In contrast to the evolutionary approach, we do not assume that the mixture inside the population will change over time as a result of a selection process. Rather, we assume that players may change their behavior as a result of individual learning. Players are modeled as automatons that adopt a given type of behavior according to some probability distribution that evolves over time with the observations players make in each period. At time $t > 1$, player i adopts a reciprocal behavior with probability P_t^i and a strategic behavior with probability $1 - P_t^i$. If he is strategic, he adopts in period t an instigator behavior with (conditional) probability Q_t and plays the single-shot dominant strategy with probability $1 - Q_t$. The general structure of the model is illustrated by figure 9.

The model assumes that each behavior has some initial *propensity*, and that the probability to adopt a given type of behavior depends on the relative propensity. Let $\alpha_t^{R,i}$ be player i's propensity to be reciprocal in period t, and $\alpha_t^{S,i}$ player i's propensity to be

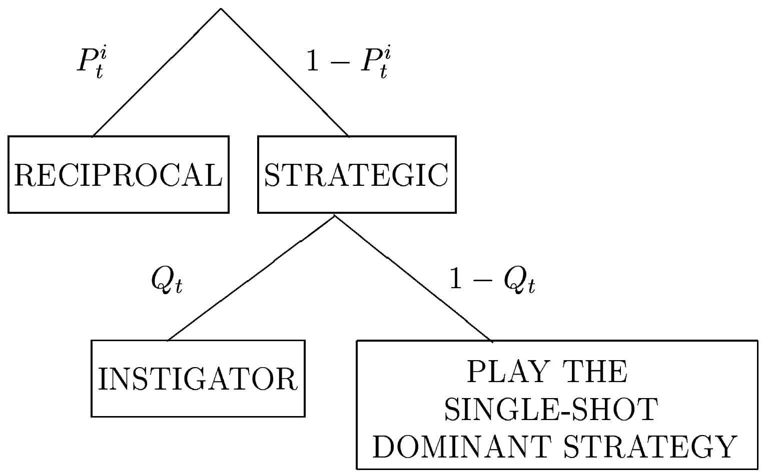


Figure 9: General structure of the model.

strategic in period t. As we shall explain below, the initial propensities of the players are revised in each period, according to the behavior they have chosen and the average level of contribution observed in the group. Probabilities are therefore updated as a result of the change in relative propensity.

To simulate our model we need an assumption about the initial level of contribution, since our model does not explain the initial level of contribution.[6] We take therefore, as initial conditions for the model, the levels of average contribution observed in period 1 in our experiment (see column 3 in table 3). In the simulated model the propensities come into play only in period 2. We assume that in period 2 each player has the same initial propensity $\alpha_2^S \in]0, +\infty[$ to be strategic and the same initial propensity $\alpha_2^R \in]0, +\infty[$ to be reciprocal. We assume that the propensity to adopt a given behavior can vary only if that behavior has been adopted by the player in the previous period. For example, if player i adopted a reciprocal behavior in period $t-1$, his propensity to adopt a reciprocal behavior in period t can increase or decrease, but his propensity to adopt a strategic behavior remains the same. However, the probability to adopt a given behavior does vary from one period to another, even if its propensity is unchanged. This is because the probability to adopt a given behavior depends not on the absolute, but on the relative propensity.

We now introduce the rules by which the probabilities of adopting a given behavior are updated as the play of the game proceeds. Let $\bar{\eta}_t = (\bar{c}_t - c^*)/(20 - c^*)$ denote the group's average rate of overcontribution in period t.

• Reciprocal behavior

Equation (6) defines the probability that player i adopts a reciprocal behavior and the dynamics of his propensity to be reciprocal:

$$P_t^i = \frac{\alpha_t^{R,i}}{\alpha_t^{S,i} + \alpha_t^{R,i}} \tag{6}$$

with

$$\alpha_t^{R,i} = \alpha_{t-1}^{R,i} + \bar{\eta}_{t-1} + \frac{\bar{c}_{t-1} - c_{t-1}^i}{20 - c^*}.$$

Player i's propensity to be reciprocal in period t depends on the propensity in period $t-1$, the average rate of overcontribution observed in period $t-1$ and the relative overcontribution of the player compared to his group in period $t-1$. If, in the previous period, the average level of contribution of the group is larger than the level of contribution of player i, the propensity to become reciprocal increases for player i. On the other hand, if player i did contribute more than the group average in period $t-1$, his propensity to be reciprocal decreases in period t. If we interpret the average contribution to the public good as the average effort of the group, the general principle is that each reciprocal agent updates his propensity to be reciprocal by adjusting his private contribution effort to the average effort of the group.

- **Strategic behavior**

The probability of player i to adopt a strategic behavior is defined as the complementary probability of the reciprocal behavior:

$$1 - P_t^i = \frac{\alpha_t^{S,i}}{\alpha_t^{S,i} + \alpha_t^{R,i}} \tag{7}$$

with

$$\alpha_t^{S,i} = \alpha_{t-1}^{S,i} - \bar{\eta}_{t-1} + \frac{c_{t-1}^i - \bar{c}_{t-1}}{20 - c^*}.$$

In contrast to the propensity of reciprocal behavior, we assume that the propensity to be strategic decreases with the average rate of overcontribution. But if player i contributes more than the group, his propensity to become strategic does increase. The idea is that a strategic player who realizes that he contributed more than the group average, will try to compensate the costs of his past contribution efforts by adjusting his current contribution towards the single-shot dominant strategy, which implies increasing the propensity to play that strategy.

If player i is strategic, there is a probability that he will also be instigator. The probability to become instigator for a strategic player is larger in early periods and decreases as the number of remaining period diminishes. We define therefore Q_t as:

$$Q_t = \left(\frac{T - t}{T}\right)^{1-\bar{\eta}_{t-1}} \tag{8}$$

where T is the total number of periods of the game. The expression in brackets measures the remaining time before the end of the game, in proportion of the total number of periods. As time passes, the strategic player's probability to adopt an instigator behavior declines. But the rate at which this probability declines depends on the relative success of past attempts to persuade others to contribute. If the instigator's strategy was successful in previous periods, the observed group's average rate of overcontribution ($\bar{\eta}_{t-1}$) is high and therefore the probability of adopting an instigator behavior in the current period is declining only slowly with t. On the other hand if $\bar{\eta}_{t-1}$ takes a low value the probability to adopt an instigator behavior in the current period is declining rapidly with t. Note that whatever the level of $\bar{\eta}_{T-1}$, the strategic player's probability of adopting the instigator behavior is equal to zero in the last period ($t = T$).

It remains to define the level of contribution that corresponds to the instigator behavior. We must take into account the fact that deviations are costly for strategic players. Therefore, strategic players are more likely to make only small overcontributions rather than large ones. The instigator's contribution is defined by $c^* + \tilde{\rho}$, where $\tilde{\rho}$ is a random variable that measures the player's overcontribution. The realization of $\tilde{\rho}$, ρ, can take any value in the set $\{1, 2, \ldots, 20 - c^*\}$. We define ρ as the "level of instigation". Let $\prod(\rho)$ measure the player's payoff[7] if he chooses the level of instigation ρ, and let $\mu(\bar{c}_{t-1})$ be a parameter that depends on the average level of contribution observed in the previous period. We assume that:

$$Prob(\tilde{\rho} = \rho) = \frac{\exp\left(\frac{\prod(\rho)}{\mu(\bar{c}_{t-1})}\right)}{\sum_{k=1}^{20-c^*} \exp\left(\frac{\prod(k)}{\mu(\bar{c}_{t-1})}\right)} \tag{9}$$

If $\mu(\bar{c}_{t-1})$ approaches infinity the probability distribution becomes uniform, while if $\mu(\bar{c}_{t-1})$ tends to zero there is a high probability that the player chooses $\rho = 1$, the lowest level of overcontribution. The parameter $\mu(\bar{c}_{t-1})$ measures the instigator's propensity to overcontribute. Since $0 \leq \bar{\eta}_{t-1} \leq 1$, in order to allow for the possibility that eventually $\mu(\bar{c}_{t-1})$ becomes very large, we arbitrarily set $\mu(\bar{c}_{t-1}) = 10^{10\bar{\eta}_{t-1}}$. Note that if the rate of overcontribution approaches zero, $\mu(\bar{c}_{t-1})$ becomes one and the player adopts his minimum level of overcontribution almost surely. This model favors levels of incentives which sustain cooperation rather than incentives which try to increase the level of cooperation by contributing more than the average contribution of the group. We prefer to model instigator behavior in this way because it seems to fit better the type of behavior observed in our experiment.

6 Simulation results

The model has three free parameters: $\bar{c}_1$, the initial average level of contribution in the group, α_2^R, the initial propensity to adopt a reciprocal behavior and α_2^S, the initial propensity to adopt a strategic behavior. We decided to run only simulations with an equal initial propensity to be reciprocal and strategic: $\alpha_2^R = \alpha_2^S = \alpha_2$. In each treatment, we set the value of $\bar{c}_1$ at the level observed in the experiment. Since we have four groups in each treatment, we define a "*simulation result*" as the average obtained over four sub-simulations. Each sub-simulation is based on the initial level of contribution observed in one of the four groups. For example, for the L treatment we run a first sub-simulation with $\bar{c}_1 = 8.5$, a second with $\bar{c}_1 = 13.25$, a third with $\bar{c}_1 = 13.5$ and a fourth with $\bar{c}_1 = 10.75$. Having made these conventions it remains to study the effect of the level of α_2, the initial level of the propensity to adopt a given behavior. For each of the four treatments we considered 10 different levels of α_2 ($\alpha_2 = 1, \ldots, 10$). When $\alpha_2 < 1$, the evolution of the average contribution becomes highly volatile. Since this outcome does not correspond to what is observed in the experiment, we considered only values of α_2 at least equal to 1. For values of α_2 larger than 10, the probability to adopt a given behavior becomes almost invariant from one period to another, which corresponds to a situation where learning is almost absent.

We run a total of 1600 sub-simulations that we summarized, as explained above, in 400 *simulation results*. Indeed, for a given α_2, each simulation was replicated 10 times with the same parameter values and with a number of periods equal to 25 ($T = 25$). Table 4 summarizes the average rates of overcontribution (averaged over all 25 periods and over all 10 replications) obtained with the simulations for the four treatments (the corresponding average contributions are given in brackets). As can be seen, for the different values of α_2 the average results over all simulations show that the levels of overcontribution for the three first treatments have the following order: $\bar{\eta}(L) > \bar{\eta}(M) > \bar{\eta}(H)$, where $\bar{\eta}(X)$ is the simulated overcontribution rate for the X treatment averaged over all 25 periods and over all 10 replications. Besides, the average rates of overcontribution for treatment VH are comparable to those of treatment M. These results corroborate what we observed in the lab. Recall that there is a significant difference between the average level of contribution and the equilibrium prediction only in the low equilibrium condition. On the other hand, the average simulated rates of overcontribution are almost always greater than those deduced from the experimental data (exceptions are for $\alpha_2 = 9, 10$ in treatment L and for $\alpha_2 = 8$ in treatment M). This result can be explained by the fact that our model does not account for all the levels of contribution that we observed in the experiment. More specifically, we did not try to account for "undercontribution", which was quite frequent, especially for the high equilibrium condition.[8]

Value of α_2	**L treatment**	**M treatment**	**H treatment**	**VH treatment**
1	39.19 % (12.10)	34.05 % (13.41)	14.59 % (14.02)	30.69 % (17.92)
2	40.48 % (12.26)	33.08 % (13.31)	17.36 % (14.22)	33.58 % (18.01)
3	38.40 % (11.99)	23.91 % (12.39)	12.94 % (13.91)	30.25 % (17.91)
4	34.13 % (11.44)	22.83 % (12.28)	14.34 % (14)	37.50 % (18.13)
5	44.77 % (12.82)	27.35 % (12.74)	17.32 % (14.21)	27.75 % (17.83)
6	37.93 % (11.93)	24.63 % (12.46)	14.52 % (14.02)	19.67 % (17.59)
7	34.27 % (11.46)	24.53 % (12.45)	16.01 % (14.12)	22.93 % (17.69)
8	38.90 % (12.06)	19 % (11.90)	12.18 % (13.85)	21.83 % (17.66)
9	28 % (10.64)	21.04 % (12.10)	10.04 % (13.70)	23.75 % (17.71)
10	27.71 % (10.60)	20.68 % (12.07)	10.63 % (13.74)	25.54 % (17.77)
Average	**36.38 % (11.73)**	**25.11 % (12.51)**	**13.99 % (13.98)**	**27.35 % (17.82)**

Table 4: Simulated average rates of overcontribution for each value of α_2.

Table 5 summarizes the simulated results for the last period (period 25) averaged over all 10 replications (the corresponding average contributions are given in brackets). The experimental average overcontribution rates in period 25 were 15.39%, −3.12% and −23.21% respectively for the L treatment, the M treatment and the H treatment. Once again, and as long as we reduce our analysis to the ordering of treatments with respect to their overcontribution rates (i.e. $\bar{\eta}_{25}(L) > \bar{\eta}_{25}(M) > \bar{\eta}_{25}(H)$, where $\bar{\eta}_{25}(X)$ is the simulated overcontribution rate for the X treatment averaged over all 10 replications in the last period), simulated results are in accordance with experimental data. On the contrary, in the VH treatment, the simulations produce a much lower average overcontribution rate in period 25 than the experimental data (equal to 33.33%) except for $\alpha_2 = 1$. This difference is due to the unusual end-effect in the VH treatment, which is the only treatment for which the average contribution increases in the last period. Nevertheless, as in the other treatments, the difference in the last period of the experiment between the average contribution and

Value of α_2	L treatment	M treatment	H treatment	VH treatment
1	36.54 % (11.75)	35 % (13.50)	9.29 % (13.65)	31.7 % (17.95)
2	26.92 % (10.50)	22.50 % (12.25)	10.84 % (13.76)	22.92 % (17.69)
3	18.27 % (9.38)	7.50 % (10.75)	5.36 % (13.38)	22.92 % (17.69)
4	14.9 % (8.94)	10 % (11)	2.59 % (13.18)	20.83 % (17.63)
5	24.52 % (10.19)	5 % (10.50)	2.68 % (13.19)	12.5 % (17.38)
6	16.83 % (9.19)	3.75 % (10.38)	4.91 % (13.34)	0 % (17)
7	19.9 % (9.59)	7.5 % (10.75)	0 % (13)	0 % (17)
8	6.89 % (7.90)	1.25 % (10.13)	3.57 % (13.25)	8.33 % (17.25)
9	4.57 % (7.59)	1.38 % (10.14)	0 % (13)	4.17 % (17.13)
10	3.37 % (7.44)	1.88 % (10.19)	0 % (13)	6.25 % (17.19)
Average	**17.27 % (9.24)**	**9.58 % (10.96)**	**3.92 % (13.27)**	**12.96 % (17.39)**

Table 5: Simulated average rates of overcontribution in period 25 for each value of α_2.

the equilibrium prediction is *not* significant.

Figure 10 (see appendix) shows the time paths of the average simulated overcontribution rates to the public good for each value of α_2 and each treatment, after averaging over the 10 replications. We kept the same graphical conventions as in figures 7 and 8. As can be seen from these figures, several patterns that we observed in our experimental results are replicated in the simulations. Except for values of α_2 equal to 6 and 8 where we observe crossing points in periods close to the end, the average overcontribution curve for the L treatment is always above the average overcontribution curve for the M treatment which is itself always above the average overcontribution curve for the H treatment. Furthermore, the average overcontribution curve for the VH treatment intersects each of the three other average overcontribution curves. Another pattern that is replicated by the simulations is the initial rise of the level of overcontribution. Remember that in the experiment, for the L treatment, the M treatment, and the VH treatment we observed that the rate of overcontribution increases until period 4. For most values of α_2 we replicated the same pattern in the simulations. While we did not observe the same evolution in the case of treatment H, the simulations results still mimic the pattern of the experimental data.

As can be seen from figure 10, for low levels of α_2 ($\alpha_2 = 1, 2$), the time paths of the overcontribution rates are relatively flat, especially towards the end of the game. This is due to the fact that for low levels of α_2 instigators have a high probability to become reciprocal if their instigator strategy was successful. When α_2 is low, the relative impact of the average rate of overcontribution in the group on the propensity to be strategic is strong, increasing the probability to become reciprocal. Therefore, sustained cooperation in early periods contributes to decrease continuously the probability to become strategic. For values of α_2 larger or equal to 3, we observe a downward trend of the overcontribution rates, in accordance with our own experimental data as well as with standard data. Moreover, this general pattern meets the behavioral hypotheses of our model. For relatively "high" values of α_2 ($\alpha_2 = 8, 9, 10$) we observe a relatively sharp decrease towards the equilibrium level of overcontribution, which ends up at zero overcontribution in period 25. This is due to the fact that for high values of α_2 the model behaves nearly as a fixed types model, because of the relatively low impact on the propensities of the rate of overcontribution. As we already pointed out, in a fixed types model, cooperation is not sustainable even with a single strategic player. Over time (excluding period 1) strategic behavior was adopted only in 9.9% of the cases for $\alpha_2 = 1$, but in 39.6% of the cases for $\alpha_2 = 10$. In the latter case, this frequency is close to the period 2 starting proportion of strategic behaviors (50%). Since sustained cooperation and decreasing overcontribution over time are the most important facts of the experimental litterature on voluntary contributions, our model provides the best description for intermediary values of α_2 $(3 \leq \alpha_2 \leq 7)$.

Our simulations were based on the assumption that $\alpha_2^R = \alpha_2^S = \alpha_2 \in \{1, 2, \ldots, 10\}$, so that in period 2 there is a 50% proportion of each behavior. Alternatively, the 50% proportion of each behavior could have been obtained by setting $\alpha_2^R \simeq 0$ for two of the players and $\alpha_2^S \simeq 0$ for the two remaining players, and taking the same value of α_2 for all the non-null propensities.[9] Simulations results obtained under this alternative setting are not qualitatively different from the ones we obtained with the setting that we presented. For low values of α_2 the contribution path is "flat" and for high values of α_2 it becomes decreasing. However, this alternative setting is more indicated for comparing the contribution paths for different initial proportions of behaviours.

7 Conclusion

We designed a public good experiment to study the impact of the equilibrium level of contribution on the subjects' contributions to the public good. The major finding of our experiment is that overcontribution is not a systematic outcome when partial contribution to the public good is the single-shot dominant strategy. We observe significant overcontribution at the low level of equilibrium contribution but not at the higher levels of equilibrium contribution. In order to explain the observed differences between the different equilibrium conditions, a simple model has been presented. Our simulations show that this model describes our experimental data rather well.

The model has two basic features: *coexistence* of two types of behavior –*reciprocal* and *strategic*– and "variable types". Strategic behavior is oriented towards individual payoff maximisation, while reciprocal behavior is motivated by gift exchange. Reciprocal agents therefore adjust myopically their current contribution to the observed average group contribution in the previous period. Strategic agents, on the other hand, adopt forward-looking strategies. But as pointed out by Fehr and Gächter (1998), the existence of reciprocal agents changes the behavior of the selfish agents. The existence of positive reciprocity induces selfish agents to behave nicely for purely selfish reasons because they can expect a reward from the reciprocal agents. The second basic feature is that agents are not of a *fixed type* but we allow them to change their behavior from one period to the next. Each agent has some initial propensity to adopt a reciprocal behavior or a strategic behavior. While Roth and Erev (1995) defined propensities over strategies, in our model we assume that each agent has a propensity to be strategic and a propensity to be reciprocal. Propensities evolve with individual experience, but in a given period the propensity of a given behavior can change only if that behavior was adopted in the previous period. In each period, each behavior can be adopted by an agent with some positive probability which depends on the relative propensities. Moreover, strategic agents can also adopt an "instigator strategy" aimed at inducing sustained cooperation from the reciprocal agents. Although our model is based on variable types, it behaves like a fixed type model if one of the initial propensities is sufficiently high while the other is close to zero. In such a case, experience has a negligible impact on the propensities. Future research will explore systematically the impact of various combinations of initial propensities on the evolution of the contribution level.

This model can be used to simulate various situations by changing the group sizes, the number of periods, the equilibrium level of contribution, the strategy space. For example, we simulated Isaac and Walker (1988) experiment relying on their own data. Isaac and Walker (1988) used groups of 4 and 10 subjects, engaged in a ten-period repeated public goods game with a corner solution, and $MPCR$s of 0.3 and 0.75. Since they have a zero equilibrium contribution solution, and since negative contributions are not allowed, our model can capture all the levels of contribution. As expected, our simulation results corroborate even better their data than our own.

Despite its capacity to explain the observed dynamics, our model can be completed in two respects: first, by incorporating the first period level of contribution, and second, by allowing undercontribution with respect to the equilibrium level of contribution. While the second task is mainly a refinement of the model, for example by taking into account decision errors, the first task is more difficult and would probably require a separate model. Furthermore, the initial level of contribution is not yet well understood, since the variables that generate it are not identified.

Acknowledgments

This work has benefited from discussions with Jean-Christophe Vergnaud. We are grateful to Frederic Koessler and Guillaume Haeringer for helpful comments on preliminary versions of the paper. Also gratefully acknowledged are numerous discussions with the participants of the following conferences, at which earlier versions of this paper were presented: the Economic Science Association annual meeting, Lake Tahoe, May 1999; the Ninth International Conference on the Foundations and Applications of Utility, Risk and Decision Theory, Marrakech, June 1999; and the 16èmes Journées de Micro-Economie Appliquée, Lyon, June 1999. Our special thanks to Gary Charness who suggested us to add the VH treatment in our experimental work.

Notes

[1]Andreoni (1993) and Chan, Godby, Mestelman, and Muller (1997) also showed that by moving the lower boundary towards the Nash equilibrium level does significantly decrease the rate of overcontribution.

[2]Only entire tokens could be handled.

[3]To obtain this result θ must be strictly larger than 10.

[4]Based on an application developed by BounMy (1998) designed for Visual Basic.

[5]When negative reciprocity is allowed, the relations among agents are even more complex, since selfish agents not only try to exploit the positive reciprocity from their environment, but try to avoid punishment by deceaved reciprocal agents. Evidence on fear of punishment in a public goods environment with negative reciprocity can be found in Fehr and Gächter (1996).

[6]Following Friedman (1998) we believe that initial choice is a separate problem from how people learn from experience.

[7]Note that in expression (9) the player's payoff reduces to $41x_i - x_i{}^2 + \theta c_i$ since the externality from the contribution of the other players is cancelled out since it appears both at the numerator and the denominator.

[8]In the high equilibrium condition, the lowest frequency of contributions below the equilibrium level, which is equal to 14%, was observed in a group where the average overcontribution rate is equal to 8.57%, which is more in accordance with our simulation results. The total frequency of the contributions below the

equilibrium level are 11.50%, 23%, 31.50% and 13.75% respectively for the L treatment, the M treatment, the H treatment and the VH treatment.

[9]In the latter case, types can remain fixed even after period 2 if the values of the high propensities are large enough.

References

Andreoni, J. (1990): "Impure Altruism and Donations to Public Goods: A Theory of Warm-Glow Giving?," *Economic Journal*, 100, 464–477.

——— (1993): "An Experimental Test of the Public Goods Crowding-Out Hypothesis," *American Economic Review*, 83, 1317–1327.

——— (1995): "Cooperation in Public Goods Experiments: Kindness or Confusion?," *American Economic Review*, 85, 891–904.

BounMy, K. (1998): "A VB Software for Experiments on Public Goods," BETA, CNRS.

Chan, K., R. Godby, S. Mestelman, and R. A. Muller (1997): "Crowding-Out Voluntary Contributions to Public Goods," Working Paper, McMaster University.

Dawes, R., J. McTavish, and H. Shaklee (1977): "Behavior, Communication, and Assumptions about other People's Behavior in a Commons Dilemma Situation," *Journal of Personality and Social Psychology*, 35, 1–11.

Fehr, E., and S. Gächter (1996): "Cooperation and Punishment – An Experimental Analysis of Norm Formation and Norm Enforcement," Discussion Paper, Institute for Empirical Research in Economics, University of Zürich.

——— (1998): "Reciprocity and Economics. The Economic Implications of Homo Reciprocans," *European Economic Review*, 42, 845–859.

Friedman, D. (1998): "Evolutionary Economics Goes Mainstream: A Review of the Theory of Learning in Games," *Journal of Evolutionary Economics*, 8, 423–432.

Holt, C. A., and S. K. Laury (forthcoming): "Theoretical Explanations of Treatment Effects in Voluntary Contributions Experiments," Handbook of Experimental Economic Results.

Isaac, R. M., and J. Walker (1988): "Group Size Effects in Public Goods Provision: The Voluntary Contribution Mechanism," *Quarterly Journal of Economics*, 103, 179–200.

——— (1998): "Nash as an Organizing Principle in the Voluntary Provision of Public Goods: Experimental Evidence," *Experimental Economics*, 1, 191–206.

Keser, C. (1996): "Voluntary Contributions to a Public Good when Partial Contribution is a Dominant Strategy," *Economics Letters*, 50, 359–366.

Kreps, D. M., P. Milgrom, J. Roberts, and R. Wilson (1982): "Rational Cooperation in the Finitely Repeated Prisoners' Dilemma," *Journal of Economic Theory*, 27, 245–252.

Laury, S. K., and C. A. Holt (forthcoming): "Voluntary Provision of Public Goods: Experimental Results with Interior Nash Equilibria," Handbook of Experimental Economic Results.

Ledyard, J. O. (1995): "Public Goods: A Survey of Experimental Research," in J. Kagel and A. Roth (eds.), The Handbook of Experimental Economics. Princeton University Press.

Marwell, G., and R. E. Ames (1979): "Experiments on the Provision of Public Goods I: Resources, Interest, Group Size, and the Free-Rider Problem," *American Journal of Sociology*, 84, 1335–1360.

Palfrey, T., and J. Prisbey (1997): "Anomalous Behavior in Linear Public Goods Experiments: How Much and Why?," *American Economic Review*, 87, 829–846.

Roth, A. E., and I. Erev (1995): "Learning in Extensive-Form Games: Experimental Data and Simple Dynamic Models in the Intermediate Term," *Games and Economic Behavior*, Special Issue: Nobel Symposium, 164–212.

Sefton, M., and R. Steinberg (1996): "Reward Structures in Public Good Experiments," *Journal of Public Economics*, 61, 263–287.

Sonnemans, J., A. Schram, and T. Offerman (1999): "Strategic behavior in public good games: when partners drift apart," *Economics Letters*, 62, 35–41.

van Dijk, F., J. Sonnemans, and F. van Winden (1997): "Social Ties in a Public Good Experiment," Working Paper, University of Amsterdam.

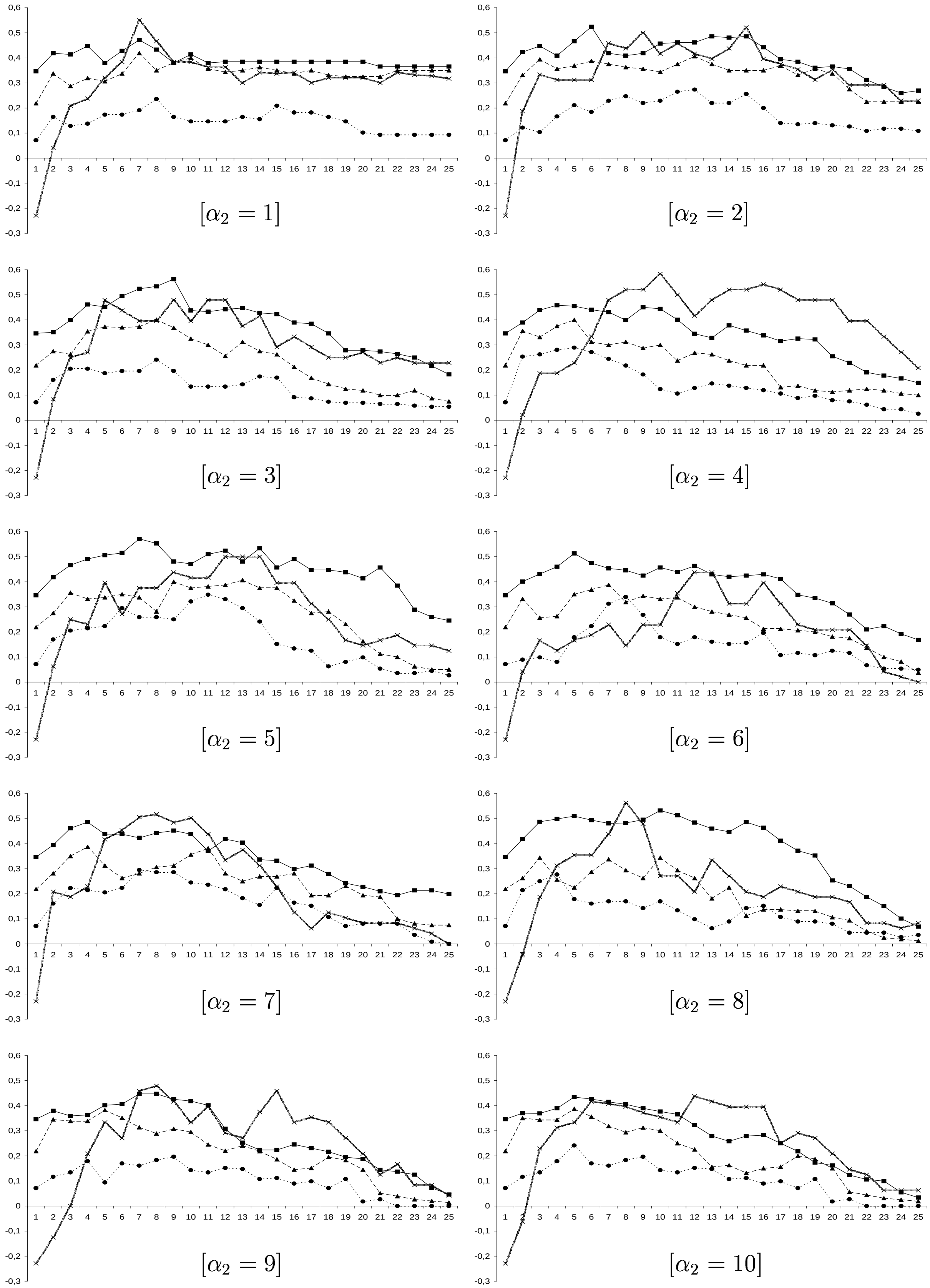


Figure 10: Time paths of the average simulated overcontribution rates for the different values of α_2.