Public Goods through Taxation in a General Equilibrium Economy: Experimental Evidence*

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Abstract

We use a laboratory experiment to compare general equilibrium economies in which agents individually allocate their private goods among consumption, investment in production and maintenance of a depreciating public facility. The public facility is financed either by voluntary anonymous contributions (VAC) or taxes. We find that rates of taxation chosen by majority vote remain at an intermediate level, converging neither to zero nor to 100%, and the experimental economies sustain public goods at levels between the finite- and infinite-horizon optima. This contrasts with a rapid decline of public goods under voluntary anonymous contributions (VAC). Both the payoff efficiency and production of private goods are higher when taxes are set endogenously instead of being fixed at the optimum level. When subjects choose between VAC and taxation, 23 out of 24 majority votes favor taxation.

Key Words: Public goods, experiment, voting, taxation, evolution of institutions.

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1. Introduction

Given the prevalence and importance of public goods in society, ways of financing their production have attracted much interest.[1] Game theoretic models suggest that egoistic individuals have little reason to finance production of public goods through individual voluntary anonymous contributions (VAC). Laboratory public good experiments tend initially to yield average contributions around 50 percent of the collective optimum, gradually declining towards a 5-20 percent range.

There is little reason for society to confine its search for efficient solutions for the pervasive problem of financing the provision of public goods (PGs) and common pool resources (CPRs) to only VACs. Institutions may evolve to address various problems of economizing through socio-political and economic processes of adjustment, experimentation, and feedback over rules, expectations, and conventions. It is reasonable to conjecture that the scope of such social evolution includes the provision of PGs and CPRs. In modern democratic societies taxes, set by an elected government, are the most common way to finance such goods.[2] We therefore explore how efficient the provision of PGs is in a system with taxes set

[1] For surveys of the substantial pre-1995 literature on experimental gaming with public goods see Ledyard (1995) and Bergstom et al. (1986). From considerable literature since then, we mention only a few. Fehr and Gächter (2000) consider public goods experiments without punishment for free riding; Brandts and Schram (2001) consider voluntary contribution mechanisms for public goods; Palfrey and Prisbrey (1997) consider public goods provision where the individuals have different marginal values for their private goods; Ahn et al. (2009) present an experiments on endogenous group sizes; Hatzipanayotou and Michael (2001) deal with public goods, tax policies and unemployment in less developed countries. Modeling in the last of these papers is closer to the spirit of our own emphasis on the importance of institutional structures in the economy.

[2] Capital cost of creating a new public good facility is typically considerably more than the cost to operate and maintain an existing facility. The two may also differ in their political feasibility. In the present model and experiment, we confine ourselves to consideration of financing the operation and maintenance of an existing public good facility in absence of uncertainty; smooth incremental additions to stock are assumed to be feasible.

by subjects through a vote. In an additional treatment subjects can also vote on whether they want to implement a system with taxes or with VACs.

Walker et al. (2000) seem to have been the first to consider the efficiency implications of a combined common-property-with-voting allocation scheme in the laboratory. They reported that voting on the use of a CPR is more efficient than appropriation of the resource by individual members of the group. In most cases proposals adopted by vote are socially optimal, indicating that groups can coordinate on efficient use of a CPR. Already Ostrom et al. (1992) showed that communication in a CPR-game significantly increased average net yield. Magreiter et al. (2005) studied asymmetric endowments and found that homogeneity makes efficient agreement more likely. However, the common-property setting of these three studies is quite distinct from the public good we explore here. Kroll et al. (2007) employ a more familiar public-goods setting and report that voting by itself does not promote cooperation; the ability of voters to punish defectors does. With perfect enforcement they observed 100 percent contribution rates in most periods. While these results are useful, contributions or a tax of 100 percent are neither realistic nor desirable in practice. In the present study, we explore an economy with private and public goods where voting is used to determine the tax rate in a setting where the optimum rates of consumption and taxation lie at an intermediate level.

Prior experimental studies (see Carpenter 2000, for an overview) have observed cooperation where conventional theory predicts it will not occur. We also build on studies of experimental production economies with taxation, e.g., Riedl and van Winden (2007). The endogenous taxation through voting is similar to the work of Sutter and Weck-Hannemann (2003, 2004). In our process-oriented strategic market game the maintenance of an existing public goods is financed through a tax on private income. The unique equilibrium solution for any given tax rate yields an optimal consumption/investment policy for each individual. General dynamic programming analysis of our basic model enables us to solve for an optimal rate of taxation for society as a whole.[3]

We set up and examine a model economy in the laboratory under two sets of conditions: (1) when the tax rate is exogenously fixed at the theoretical optimum (knowable only to an omniscient government); and (2) when the rate of taxation is set and adjusted through a democratic voting process. As a comparison and bridge to existing literature, we also examine the performance of otherwise identical economies in which taxation is replaced by individual VACs. In a supplementary treatment we let the subjects choose between VACs and taxation systems by majority vote.

Our 2x2 (+2) design has four main and two supplemental treatments (see Table 1). Of the four, Treatment 1 has a given tax rate and the starting stock of the public good is at the GE optimum, contrasted with starting at 50 percent of the optimum in Treatment 2. The taxation is set exogenously at the theoretical optimal level to maintain the optimal stock of the public good facility in both cases.[4] In Treatments 3 and 4, the tax rate is set endogenously through subjects' vote (at the median choice) once every five periods, starting with optimal and suboptimal public facility levels in Treatments 3 and 4, respectively.

In order to compare and contrast our results with the voluminous VAC literature, we supplement our 2x2 experimental design with treatment T0 which starts with the optimal level of PGs (as in Treatments 1 and 3), but taxation is

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[3] Appendix A presents an EXCEL-sheet (the infinite-horizon model can be found at http://www.uibk.ac.at/ibf/mitarbeiter/huberj/model_infinite_online-material.xls, while the finite-horizon model is at http://www.uibk.ac.at/ibf/mitarbeiter/huberj/model_finite_online-material.xls) which allows one to manipulate different input variables of the model and see the charts of respective changes in utility and other variables.
[4] For the basic model of tax-financed public goods, see Karatzas et al. 2006..

replaced by VACs. In the second supplemental treatment, T5, we aim to capture a part of the dynamics of the political process by letting the subjects choose between the VAC and taxation systems by a majority vote, and implementing their chosen regime.

We find that the four main treatments with finite horizon experimental economies sustain public goods between the finite- and infinite-horizon optima, and exhibit 90 to 100 percent efficiency. Efficiency and production of private goods are higher when the rate of taxation is determined by voting compared to being fixed at the GE optimum. In the two voting treatments taxes remain at an intermediate level, converging neither to zero nor to 100%. Irrespective of whether we start at 50% or 100% of the optimum, the stock of the public good converges near the same level between the infinite- and finite-horizon optima. This holds also in the supplemental treatment T5 in which the majority chose taxation regime over VACs 23 out of 24 times. In all except the VAC treatments, the ending stock of public goods exceeds the finite horizon optimum. We also find that the share of total earnings derived from the public good is higher in the taxation-treatments; in VAC treatments most earnings come from direct consumption of the private good. Total production of private goods is not reduced by taxes, and is highest when subjects can choose the tax rate endogenously (compared to VACs or externally fixed tax rate). These results from a general equilibrium laboratory economy suggest that taxation is an efficient social institution to address the problem of under-production of public goods through voluntary contributions. The model and experimental design are presented in Section 2, followed by results, and a discussion in the subsequent sections of the paper.

2. A Dynamic Equilibrium Model of an Economy with a Public Good and its Experimental Implementation

We consider a version of Samuelson's (1954) pure public good embedded in a parallel dynamic programming control process that has been solved for its type-symmetric non-cooperative (rational expectations) equilibrium for any tax rate (see Karatzas et al. 2011).[5] The dynamic structure of the game also includes a government and voting.

The basic model involves the maintenance of a depreciating public good facility such as a transportation or sewage system (see Karatzas et al. 2006 for a description).[6] The game has a government and n individual agents; each agent is initially endowed with a quantity of private goods and money (a, m). The government is endowed with G units of the public good and M units of money at the outset. It also has the right to collect as tax a fraction θ of individuals' income from the sale of private goods, and a production function that transforms the private goods bought from tax revenues into the public good.[7]

A move by an agent i in any period t is to decide how much money to bid (b_{ti}) to buy private goods in the market[8] and, after she receives the private good from the market, how much to consume and how much to put into production for

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[5] Formally, with a continuum of agents we solved for any tax level; then after solving this set with taxation level as a parameter we solved for the optimum from the point of view of a benevolent central government. The theory approximates equilibrium as though the number of agents is large enough that they have no influence on the price. Use of n =10 in the experiment, ignores the presence of a small oligopolistic influence.

[6] It also could be a wage-supported bureaucracy that provides a self-policing system for the economy. Although bureaucracy could be one of the most important and earliest of costs of public goods, it is rarely mentioned in discussions of public goods.

[7] Even at this level of simplicity, given that production takes time, there are accounting questions to be considered in the definition of periodic income and profits. In a stationary equilibrium the timing differences disappear.

[8] In the experiment all money is automatically bid, so b_{it}=m_{it}.

the following period. Figure 1 gives a time line of what happens within one period.

Insert Figure 1 about here

A period begins with government in possession of taxes gathered in the preceding period in the form of money (M in period 1), the n agents carrying their after-tax money balances from the previous period (m in period 1), and the units of the private good they produced at the end of the previous period (a in period 1). We use a sell-all market mechanism, in which individuals' entire balance of private goods is automatically offered for sale in a market (see Huber et al. 2010 for properties of the sell-all mechanism). In the experiment each individual automatically bids his total money balance b to buy the private good from the market. The government also bids all its money balance $\bar{b}$ for the private good. A price p is computed as the ratio of the total money bid (by agents and the government) divided by the total number of units of private goods available.

The fixed money supply in the economy in conjunction with the sell-all market game imposes a good deal of regularity on price dynamics: If aggregate production increases (decreases), then the price must fall (rise). We see this as a virtue as it promotes order in an environment with a lot of moving parts (money, private goods, public goods, taxation, production, and consumption), and permits sharper focus on the question of efficient provision of public goods under taxation.

The quantity of private goods the government and individual agents get equals the money they bid divided by the price of the private good ($k_i = b_i/p$ units for individual i; $k = \bar{b}/p$ units for the government). Each agent, being a producer as well as a consumer, divides the units bought between consumption and production.[9] In addition, each agent receives the price multiplied by the number of units sold as his income in units of money. This money income is taxed at a uniform tax rate, either pre-set to the optimum rate θ = 21.5% (in Treatments 1 and 2) or set endogenously through a vote by subjects (in Treatments 3 and 4), where all subjects pay the median of the tax rates proposed by individuals.

The n producer/consumer agents have a concave private good production function $f(k) = 80*k^{0.25}$ with a one period production time lag, and a payoff function of the form $u(x, G) = (x + G/4)$, with x being the consumption of private goods and G being the stock of public goods. We calibrated the game so that in equilibrium roughly half of the expected earnings come from the public good and the other half from private consumption.

Before the end of the period the stock of the public good is depreciated by 10%. The government then uses all k units of private good it buys to produce $F(k) = 2*k^{0.5}$ units of the public good which is added to the stock of the public good at the beginning of the next period. Depreciation is a fixed percentage of the level of capital stock – in the experiment we use 10 percent depreciation rate. The government carries the tax collected as money balance to the following period to buy private goods. In equilibrium the production of public goods precisely covers depreciation, otherwise the amount of the stock of the public good changes. This describes one full period of the game. Holdings of the goods (public and private) and cash are carried over from one period to the next in all treatments.

In implementing an experimental game with a finite termination we are faced with the question of how to value the stock of public good and money holdings at the end of the game. With zero valuation, we expect that the

[9] In this respect our experiment is similar to Lei and Noussair's (2002) growth experiment; the same subjects simultaneously play the roles of both the firm and the consumer.

maintenance of the public good facility will tend to drop off towards the end of experimental sessions. We set up an Excel sheet to numerically solve the dynamic program when the value of the stock of public good is zero at the end of the session (see footnote 3 and Appendix A). The results obtained from this optimization are labeled "finite horizon" to distinguish them from the "infinite horizon" results throughout the paper. The terminal or "salvage value" of left over money, goods and the public good are all zero. Subjects are instructed that the session will end with 1/6th chance each after period 25, 26, 27, 28, 29, or 30.[10]

Instructions given to subjects are included as Appendix B. Instructions supplemented by trial rounds allowed subjects to gain a reasonable understanding of the decisions they had to make, the opportunity sets from which various decisions had to be chosen, and how their own and others' decisions were linked to their payoffs. It is unlikely, and almost impossible, for any subjects to have fully understood the mathematical structure and properties of the model economy in this experiment (or for that matter, in most experiments where the mathematical structure is nontrivial). It is not the purpose of the experiment to assess the cognitive capacities of subjects to intuitively arrive at optimal solutions to stochastic dynamic programs; that would be outside the scope of this paper, and fall into cognitive psychology or psychological economics. Our aim is only to find out if the mathematical solutions provide a reasonable neighborhood of attraction for aggregate outcomes of the economies populated with agents having abilities and mild incentives of ordinary people.

We consider a multi-period dynamic model of a durable public good as representative of many situations in a modern mass economy. In doing so, several

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[10] For the equilibrium calculations presented in the results section we used 1/6th change of ending the game after each of the periods 25 to 30. In the experiment we ran the first session with a random termination, which happened to be after period 26. For better comparability and ease of exposition in figures all other sessions were also ended after this period.

subtle difficulties appear. In particular before optimality can be well defined, the cost of the path to an equilibrium as well as the efficient yield at equilibrium must be taken into account. If the future has little value and the maintenance of a public good is costly, one might as well forego maintenance in favor of immediate consumption. In our experiment this was avoided by selecting no discount on the future.[11] A further experimental difficulty occurs as the experiment time horizon is finite. We expect and empirically find some drop off near the end of the play as the remaining public goods are of no further value.

Implementation of the experiment

The experiment consists of variations on the regime to finance a public good (fixed tax, endogenous tax, VAC) and the initial stock of the public good the economy is endowed with (optimum, half of optimum) in a 2x2 + 2 design (see Table 1).

Insert Table 1 about here

The variations in the regime are:

- Control treatment T0 in which subjects make voluntary anonymous contributions (VAC) for production of the public good. This treatment serves as a benchmark for comparison with the results from experimental literature on VAC partial equilibrium economies.
- Exogenously fixed tax rate (at optimal level of 21.5%) in regimes T1 and T2. In T1 (and T3), the starting level of the stock of public good is at its steady state (i.e., infinite horizon) optimum of 427. However, it cannot be

[11] With zero discount rate the payoffs of a dynamic program may become unbounded; in our experiment this can be handled by maximizing the average payoff per period.

taken for granted that a government can identify and build the optimal public facilities at the optimal level in the first place. In order to assess the dynamic ability of the system to adjust when the starting point is not at the optimum, we use Treatment T2 (and T4) in which the starting level is 50% of the steady state optimum.

- Whether governments have the ability or incentives to set the rate of taxation at the optimal level is, at the very least, controversial. We therefore contrast the results of optimal exogenous tax rate economies (T1 and T2) against economies with an endogenously determined tax rate (median of individual proposals) in regimes T3 and T4; and
- Institutional evolution through voting between VAC and taxation regimes in T5.

In T3 and T4 the exogenously imposed tax rate of T1 and T2 is replaced with a rate determined by a vote of the participants every five periods. Each subject submits a tax proposal and the median of the ten proposals is chosen as the rate of taxation applied to all subjects for five periods, until the next vote is taken. Agents therefore have the collective freedom to increase or reduce the provision for public goods through voting.

In T5 subjects first experience five periods with VAC (setup of T0) and then five periods with taxes (setup of T3). Then the treatment starts where subjects collectively decide by majority vote whether they want to implement VAC or taxes for the next five periods.[12] The selected mechanism is implemented for five periods, until the next vote is taken.

Table 2 gives the values of the parameters of the experiment. The resulting stationary (i.e., infinite horizon) equilibrium price is p = 27.67. Each individual

[12] One institution was picked randomly in one occurrence of a 5:5 tie.

should buy 170 units of the private good and consume 68.27%, i.e., 116 units, while the remaining 54 units are put into production to produce $80*54^{0.25} = 217$ units for the next period. The government buys 467.7 units of the private good to produce $2*467.7^{0.5} = 43.25$ units of the public good which is just enough to offset the depreciation (10% of 427 units) of the equilibrium stock of the public good.

Table 2 about here

We conducted a total of 26 independent runs, each with a different cohort of 10 subjects for a total of 260 subjects. All subjects were BA or MA students in Management or Economics at the University of Innsbruck, Austria. All sessions were carried out using a program written in z-Tree (Fischbacher, 2007) and recruitment was done with ORSEE (Greiner, 2004). Average duration of a session was approximately 60 minutes and average earnings were 15 Euros.

3. Hypotheses

This laboratory experiment explores several key questions: (1) how VAC and taxation regimes affect the provision of a public good; (2) whether the tax rates determined by popular vote tend towards zero over time; (3) whether the steady state stock of public good depends on the initial conditions; (4) whether the efficiency of the system is affected by the regime for provision of a public good. Based on the literature discussed in the introductory section, we set up these questions in the form of null hypotheses of "no difference". Most of the tests (except on the stock of public good) are conducted on data from the final five periods of each run in order to avoid undue influence of any end-of-the-session effects; we use data for the final period for the stock of the public good because it is a cumulative and stable magnitude.

Insert Table 3 here

3.1. Endogenously set tax rates:

> *Null Hypothesis Ia: Endogenously determined tax rates stabilize near the optimal level.*
>
> *Alternative Hypothesis Ia: Endogenously determined tax rates are below the optimal level.*
>
> *Null Hypothesis Ib: Endogenously determined tax rates are zero.*
>
> *Alternative Hypothesis Ib: Endogenously determined tax rates remain above zero.*

Paying low or no taxes leaves more for private consumption initially, but ends up hurting everyone when the stock of the public good is depleted. An economy that attains general equilibrium optimum will generate tax rates near 21.5 under null hypothesis Ia. The alternative is low tax rates below the optimum level. This hypothesis is tested on data from Treatments T3 and T4. In the extreme tax rates may be zero. This is explored with Hypothesis Ib.

3.2 Public Good Provisioning under VAC and Endogenous Taxation

> *Null Hypothesis II: There is no difference between provision of public goods under taxes and VAC regimes.*
>
> *Alternative Hypothesis II: Taxation results in higher provision of public goods than VAC.*

This hypothesis is tested on data from Treatments T1 to T4 vs. T0. Most VAC literature reports low contributions to public good; if endogenously determined tax rates are an effective solution to the problem, we should expect to reject the null hypothesis in favor of the alternative.

3.3. Dependence of public good provision on initial conditions

Null Hypothesis IIIa: The final level of the public good does not depend on initial endowment of the public good.

Alternative Hypothesis IIIa: The final level of the public good is higher when the initial endowment is higher.

Null Hypothesis IIIb: The final level of the public good does not depend on whether it is financed by fixed or endogenously determined tax rates.

Alternative Hypothesis IIIb: The final level of the public good is higher when it is financed by a tax rate fixed at the optimum level.

Null Hypothesis IIIc: The final level of the public good does not depend on whether it is financed by taxes or VAC.

Alternative Hypothesis IIIc: The final level of the public good is higher when it is financed by taxes instead of VAC.

Null Hypothesis IIId: Variation in the final level of the public good across multiple sessions of treatments T1 and T3 (and across multiple treatments of T2 and T4) is equal.

Alternative Hypothesis IIId: Variation in the final level of the public good across multiple sessions of treatments T1 is lower than in T3 (and is lower in T2 than in T4.

The four sub-versions of this hypothesis are tested on the stock of the public good in the last period. We use data from (a) Treatment T1 vs. T2 and T3 vs. T4; (b) Treatment T1 vs. T3 and T2 vs. T4; (c) four comparisons of T0 against T1, T2, T3, and T4, respectively; and (d) two comparisons between T1 and T3 and between T2 and T4.

Rejection of null hypothesis IIIa suggests that the tendency of this economy to go to its equilibrium depends on the initial conditions. Rejection of null hypothesis IIIb suggests that endogeneity of tax rate determination matters.

There are strong theoretical arguments why subjects should be expected to vote for rather low tax rates (below GE level), but on the other hand earlier experimental evidence (e.g. Kroll et al., 2007) suggests high tax rates when taxes are enforceable (as they are in our case). Hence we have no clear expectation on this hypothesis. Rejection of null hypothesis IIIc suggests that the financing regimes for public goods matter for its steady state level. Rejection of null hypothesis IIId suggests that the extra degree of freedom in endogenous tax rate treatments adds to additional variability in data.

3.4.Efficiency:

We measure efficiency of the economy as the total points earned by all participating subjects in a session as a percentage of the number of points they would have earned if the economies had achieved the infinite horizon (steady state) general equilibrium outcomes. Here we use average efficiency across the last five periods.

Null Hypothesis IVa: Efficiency is the same irrespective of the initial endowment of the public good.

Alternative Hypothesis IVa: Efficiency is lower when the initial endowment of the public good is sub-optimal.

Null Hypothesis IVb: Efficiency is the same irrespective of fixed or endogenous tax rates.

Alternative Hypothesis IVb: Efficiency is lower when tax rates are determined endogenously.

Null Hypothesis IVc: Efficiency is the same irrespective of public good financing by taxation or VAC.

Alternative Hypothesis IVc: Last period efficiency is lower when the public good is financed by VAC.

Hypothesis IVa is tested by comparing data from treatments T1 vs. T2 and T3 vs. t4. Hypothesis IVb is tested by comparing data from two pairs of treatments T1 vs. T3 and T2 vs. T4. Hypothesis IVc is tested by comparing data from four pairs of treatments T0 vs. T1, T2, T3, and T4.

3.5. Production of the private good

Null Hypothesis Va: Production of the private good is the same irrespective of fixed or endogenous tax rates.

Alternative Hypothesis Va: Production of the private good is different with fixed or endogenous tax rates.

Null Hypothesis Vb: Production of the private good is the same irrespective of public good being financed by taxation or VAC.

Alternative Hypothesis Vb: Production of the private good is not the same when the public good is financed by taxation or VAC.

These two null hypotheses are given a two-tailed test because there is not relevant indication on the direction of deviation from the null in the earlier literature.

3.6. Decomposition of earnings from public goods and private consumption

Null Hypothesis VIa: Initial endowment makes no difference to the percentage of earnings from the public good.

Alternative Hypothesis VIa: Optimum level of initial endowment of public good yields a higher percentage of earnings from the public good.

Null Hypothesis VIb: The method of determining tax rate (endogenously or fixed) makes no difference to the percentage of earnings from the public good.

Alternative Hypothesis VIb: Endogenously determined tax rates generate a lower percentage of earnings from the public good.

Null Hypothesis VIc: Financing of public good by taxation or VAC makes no difference to the percentage of earnings from the public good.

Alternative Hypothesis VIc: Financing of public good by VAC results in a lower percentage of earnings from the public good.

3.7. Democratic Choice of Financing Regime

Null Hypothesis VII: There is no preference between financing the public good by VAC or taxation when citizens are given a chance to decide by popular vote.

Alternative Hypothesis VII: Subjects prefer taxation over VAC for financing the public good when citizens are given a chance to decide by popular vote.

The alternative hypothesis is consistent with the findings of Gürerk et al. (2006).

4. Results from the Experiment

Results of the experiment are organized and presented in Figures 2-7 as well as in tests of the seven hypotheses stated above. Each of Figures 2-6 charts a single measure of the outcomes of the multiple independent sessions of experimental economies with different subjects participating in each session of the four main treatments T1, T2, T3, and T4, as well as the supplemental treatment T0 (thin chain-dotted lines in the two left panels of each figure). Thick dashed lines in black and green show general equilibrium predictions for infinite and finite horizon economies as theoretical benchmarks for comparison.[13] Since these experimental economies are known to the subjects to last for a finite number of periods, strictly speaking, the thick green dashed line for finite horizon equilibrium is the appropriate benchmark for comparing the empirical data. However, we add the thick black dashed line for infinite horizon equilibrium as an additional benchmark in case subjects ignore the impending end of the economy until close to the end.

4.1. Endogenously set Tax Rates (Figure 2)

The two top panels of Figure 2 are empty because the tax rate was exogenously fixed at 21.5 percent in Treatments 1 and 2. In the left bottom panel for Treatment 3 (with the initial stock of public good at steady state level 427) the endogenously determined tax rate usually remained below 21.5 percent and declined from a range of 17.5-22 (average 19.8) in the first vote to 5-22.5 percent (average 14.3) in the sixth and final vote. Note that the finite horizon optimal tax rate (broken thick curved line) declines from 25% to near zero, because the terminal conditions assign zero value to the stock of public good at the end of the session. The endogenously determined tax rates do decline but not as rapidly; they lie between the finite- and infinite-horizon optima.

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[13] For the finite horizon benchmark each of periods 25 to 30 was assumed to have 1/6th probability of being the last period, as was also stated in instructions to subjects.

Figure 2 about here

In Treatment 4 (right bottom panel) the endogenously determined tax rates also declined slightly from range 11-23 (average 18.3 percent) in the first vote to 8-23 (average 16.3 percent) in the sixth and final vote. Compared to the finite horizon benchmark, subjects chose marginally higher tax rates, which supported a rise in the stock of public goods from the initial suboptimal level.

In all 12 endogenous taxation economies, agents voted to pay taxes higher than the finite horizon optimum in the second half of the sessions, and taxes clearly did not approach the extreme values of zero or 100%, as in earlier VAC public goods literature. The Null hypothesis Ia, on the tax rates stabilizing near the optimal (versus declining towards zero) is rejected when all tax rates are compared to the optimum of 21.5%. However, when testing each of the twelve votes (six for each of T3 and T4) separately, the null is rejected seven times and not rejected five times (among them the first vote in each of T3 and T4). Hence, while the null of Hypothesis Ia is overall rejected we have to acknowledge that tax rates were close to the infinite-horizon optimum in almost half of the individual votes. As for Hypothesis Ib: not a single vote yielded a tax rate of zero. An enforced tax that is equal for all does not lead to a break-down as is usually observed in VAC public goods experiments.

4.2 VACs vs. Taxation (Figure 2)

The chain-dotted lines in the left panel of Figure 2 show the realized VACs as a percentage of individual income in the two sessions of Treatment 0. Contributions dropped steadily over time, asymptotically approaching zero, and remained less than the finite- as well as infinite-horizon optima throughout. This is consistent with the results of prior laboratory experiments with voluntary anonymous contributions for public goods. Null hypothesis II, stating that treatments with taxes lead to the same average contributions than the treatment with VACs is clearly rejected in favor of the alternative for all periods, as well as the data from the final five periods (Wilcoxon-signed ranks tests, p-values <0.01).[14]

4.3. Stock of Public Good (Figure 3)

Next we explore the development of the stock of the public good over time and test whether it differs between treatments near the end of the experimental sessions. The top left panel in Figure 3 shows the time series of the stock of public good observed during the four independent sessions of Treatment T1 (with tax rate fixed at 21.5%, starting with the optimal stock 427 of the public good at the beginning of Period 1). Time paths of the stock of public good for each of the four sessions are shown in thin solid grey lines and the mean of the four paths is shown in a thick solid black line. Given the small dispersion of the four paths around the mean, the latter captures their central tendency well. Two thick broken lines chart the general equilibrium benchmarks – the black horizontal line at 427 for the steady state or infinite horizon equilibrium level of public good, and the curved green line for the finite horizon level with expected ending stock of public good at 310.[15,16] The same conventions are used to depict data in the other panels of Figure 3 and in Figures 4 through 7.

[14] Mann-Whitney U-test comparing average contributions per run confirm this, as all p-values are below 0.05 for four individual tests comparing each of T1, T2, T3, and T4 to T0.
[15] Since the end of the session was announced to be uncertain (1/6th chance of ending after period 25, 26, 27, 28, 29, and 30), the finite horizon equilibrium predictions are given in expected values (see Appendix A).

Insert Figure 3 about here

In all four sessions of Treatment 1 (top left panel), the stock of public good gradually but steadily declined over the 25 rounds from the starting level to a range of 355-402 (average 381), which is half-way between the steady state and finite horizon optima of 427 and 310, respectively.

The top right panel in Figure 3 shows the four runs of Treatment 2 with tax rate fixed at 21.5% but starting with 50 percent of the optimal stock of public good (213.5). In all sessions of Treatment 2, the stock of public good rose steadily to a narrow 357-366 range (average 362). So far we can conclude that with the tax rate exogenously fixed at the optimum level, the stock of the public good converges near the midpoint between the finite- and infinite-horizon levels. This holds irrespective of the starting stock of the public good.

In the bottom left panel of Figure 3 the six sessions of Treatment 3, with endogenously determined tax rates and starting with optimal stock of public good, show the stock of PG to decline over time to the range of 352-404 (average of 371). In the bottom right panel, the six sessions of Treatment 4, with endogenously determined tax rates but starting from half the optimal level of public good are presented. The stock of public good tended to rise to the range of 273-406 (average of 344).

Starting from the optimal level, the stock of public good tended to decline to the neighborhood of 370 irrespective of whether the tax rate was fixed or determined by vote by participants. Starting from the suboptimal level, the stock

[16] In an unconstrained environment, one would expect the finite horizon equilibrium stock of public good to be exhausted to zero at the end of the session. Since the stock of public good depreciates at a constant rate of 10% per period, exhaustion close to zero at the end would require lower investment in early periods. The lower payoff in those periods prevents the optimal level of public good from being driven to exhaustion at the end even in a finite-horizon economy.

of public good rose gradually to the neighborhood of 360 irrespective of whether the tax rate was fixed or determined by vote by participants. Hypotheses IIIa, compares the final stock of the PG between treatments where the stock started at the optimum vs. half of the optimum. The two Mann-Whitney U-tests deliver *p*-values of 0.248 and 0.423, for T1 vs. T2, and T3 vs. T4, respectively. Hence the null Hypothesis IIIa is not rejected.

Hypothesis IIIb compares the final stock of the PG between treatments where the tax rate is fixed at the optimum or is set endogenously. The two Mann-Whitney U-tests deliver *p*-values of 0.286 and 0.831, for T1 vs. T3, and T2 vs. T4, respectively. Hence the null Hypothesis IIIb of no difference in the final stocks of public goods under two tax policies is not rejected. It seems reasonable to infer, on the basis of these 20 independent sessions of experimental economies, that the stock of public good tends towards the range midway between the infinite-horizon and finite-horizon optima.

Finally, the two left panels of Figure 2 show, in thin chain-dotted lines, the time paths of the stock of public good in two Treatment 0 economies in which taxation was replaced by individual VACs. In these two sessions, the stock of public goods declined steadily and sharply to 147 and 170 respectively, at the end of period 25. This is much lower than levels observed in any period of any of the 20 economies with taxation. Null hypothesis IIIc of equality of the final stock of PG between VAC treatment T0 and each of T1-T4 is rejected. The *p*-values of the Mann-Whitney U-tests are 0.046 for T3 and T4, N=8, and 0.064 for T1 and T2, N=6. The data confirm that the final stock of the PG is lower in T0 with VAC than in any other treatment. These results are consistent with those obtained in voluminous experimental literature on partial equilibrium economies in which public goods are financed by VACs.

A comparison of the data in the four panels of Figure 3 reveals some differences but also strong similarities. The stock of public good showed greater dispersion across multiple independent sessions of identical economies when tax rates are endogenous, instead of being fixed (standard deviation of final PG stock across sessions is only 3.86 in T2, but 47.52 in T4, $p<0.01$ on F-test of equality of variances; no significant difference between T1 and T3). This rejects hypothesis IIId for T2 vs. T4.

4.3. Efficiency (Figure 4)

The total points earned by all subjects as a percentage of the number of points they would have earned if the economies had achieved the infinite horizon (steady state) general equilibrium outcomes is defined as the efficiency of these economies. Points earned by each individual are the private goods consumed plus the stock of the public good divided by four. In equilibrium roughly half of the points are earned from consumption and the other half from the public good.

Period-by-period efficiency for the 20 sessions are presented in the four panels of Figure 4. Note, that efficiencies for individual periods and the finite horizon benchmark (shown in thick broken curved line) can exceed 100% in some periods, because agents can earn a high but unsustainable payoff by consuming, thereby depleting the stock of the public good over time.

Insert Figure 4 about here

Visual inspection shows that efficiencies start lower in T2 and T4 than in T1 and T3 due to the lower initial stock of the PG. Also, efficiencies in T3 seem to be higher than in other treatments. In Treatment 1, with fixed tax rate and stock of the public good starting at the optimum, efficiencies started close to 100 percent and declined gradually, albeit noisily, to the range of 77-86 percent with an average of 83 percent. With suboptimal start (Treatment 2 in the top right panel) efficiencies were at 81 percent at the beginning and 83 percent at the end of the sessions. With endogenous tax rates and optimal start (Treatment 3; bottom left panel) efficiencies remained in the 90s throughout, with the maximum of 101.5 percent in the last period. Only with endogenous tax rates and suboptimal start (Treatment 4 in bottom right panel) did efficiencies show a clear rising trend from an average of 74 percent in period 1 to 91.5 percent in the last period.

Testing Hypothesis IVa with Mann-Whitney U-Tests (N=10) on the average efficiency of the last five periods we found no significant difference between T1 and T2 (p=1), but significantly higher efficiency in T3 than in T4 (p=0.016), which can be attributed to the higher initial stock of the PG in T3 which allows for higher efficiency.

Hypothesis IVb, comparing efficiency in treatments with tax rate fixed at the GE optimum of 21.5% and endogenous choice of taxes reveals significant differences, as efficiency is markedly higher in T3 than in T1 (p=0.011) and also marginally higher in T4 than in T2 (p=0.088). Hence the endogenous choice of taxes resulted in higher efficiency levels (through marginally higher stocks of the PG and marginally higher production of private goods, see next section) than with a preset tax rate.

To examine hypothesis IVc, the chain-dotted lines in the two left panels for T0 economies, with VAC, are hardly distinguishable from the lines for efficiency of T1 economies. However, efficiency in T3 was significantly higher than in T0 (Mann-Whitney U-test, p=0.046, N=6). The comparatively high (but unsustainable) efficiency in T0 resulted from high consumption of the private good, as the stock of the public good was run down because of low contributions.

4.4. Production of Private Goods (Figure 5)

Private goods in the hands of subjects can either be consumed or used for production of more private goods for the next period. Figure 5 shows the development of total production of private goods in each session. Production fell in all of the treatments, probably least (and late) in T3. Total production was similar in all treatments. This is remarkable, as it is often argues that taxation discourages production. This does obviously not hold in our experiment, as total production is actually highest in T3 where taxes are set endogenously. The thick broken lines for GE production in infinite and finite economies overlap at 2170 except in the final period when the finite period production drops.

Figure 5 about here

In all economies, the level of production was near the optimum (2170) at the outset, but declined over the 25 rounds to the neighborhood of 1,500 with considerably variation across sessions as well as across rounds.[17] A reason for this could be the choice of the concave production function ($80*k^{0.25}$) in which the extra output from positive deviations from optimal input (54 units of the private good) is much smaller than the loss of output from comparable negative deviations. Thus, while the average input is close to the optimum (average of 53.2 in the first ten periods; 44.8 overall), average output is lower due to dispersion of inputs across individual subjects. Also, optimal production would fall sharply in periods 26 to 30 in the finite-

[17] Note that production is also at 2170 in the finite-horizon-benchmark in periods 1-25, as subjects need to produce units of the private good in order to earn money and be able to consume and produce units for the next period. As the rules specify that there will certainly be at least 25 periods, production is at the long-term optimum of 2170 throughout periods 1-25. After period 25 production quickly and steadily drops.

horizon benchmark. Thus, the decline observed in the experiments is also theoretically justifiable. Also note that while private good production drops substantially throughout the session, the concavity of the public goods production function implies that not many public goods are lost at the margin

We test for differences in average production across all periods (rather than only the last five), as total production is relevant in each period and as the initial stock of PG should be irrelevant for production.

To test Hypothesis Va we run pairwise Mann-Whitney U-tests between each treatments T1 vs. T3 and T2 vs. T4. T3, which a high initial stock of the PG and endogenously set tax stands out as the treatment with the highest average production, which is significantly higher than production in T1 (but also higher than in T2 and T4, each difference significant with $p<0.02$). The other treatment with endogenously set taxes, T4, had the second highest average production, which was significantly higher than in T2 ($p=0.011$). We conclude that production was higher in treatments where subjects had control over the taxes they pay compared to those treatments where taxes were set exogenously.

To test Hypothesis Vb we run pairwise Mann-Whitney U-tests between T0 and each of T1 to T4. We find no significant differences for T1 and T4, but significantly higher production in T2 and T3 (p-values 0.064 and 0.046, respectively).

Hence, we can conclude that in our setting taxes did not deter production, when compared to an VAC-regime. When comparing tax-treatments subjects produced more when they had control over their taxes.

4.5. Share of Points Earned from the Public Good (Figure 6)

We set the variables in the game in a way to ensure that in equilibrium roughly one half of points are earned from the public good and the other half from the consumption of the private good. Figure 6 shows the percentage of points actually earned from the public good (with the remainder earned from consumption of private goods).

Figure 6 about here

In T1 and T3, where the stock of the public good started at the optimum, the share of points earned remained close to the GE level of 50 percent throughout. In T2 and T4, by contrast, the stock of the public good started at half of optimum, and the share of points earned from the public good was initially below one third. However, through high-enough taxes the stock of the public good grew over time and its contribution to total points earned rose to roughly 50 percent in the second half of the experiment in both T2 and T4.

Testing Hypotheses VIa and VIb on the averages of the last five periods we find that among the tax treatments T1 has a significantly higher ratio from the PG than T2 (rejecting null VIa) and also than T3 (rejecting null VIb). The higher ratio in T1 is not due to a higher stock of PG, but due to lower production of the private good in this treatment especially compared to T3. We do, however, find no differences between T3 vs. T4 and T2 vs. T4.

As for Hypothesis VIc: The thin chain-dotted lines in Figure 6 show the two VAC-runs. They illustrate nicely what happened in this treatment: as the stock of the public good drew down due to low contributions, the share of points earned from the public good fell from 45 percent in the first period to 22 percent in the last period. Differences between this treatment and the other four are significant (as far as they can be with only two runs in T0, with p-values of 0.046 in T0 vs. each of T3 and T4, respectively, and p=0.064 in T0 vs. T1 and T2).

4.6. Supplementary Treatment where subjects choose between taxation and VAC by vote (Figure 7)

Gürerk et al. (2006) introduced "voting by feet" dynamics in a traditional public goods setting. Two institutions ran simultaneously in their experiment. Both institutions had VACs, but punishment (sanctioning) was possible in only one of them. They found that contributions in the sanctioning institution converged towards 100%, and to 0% in the sanction-free environment. While initially some 70% of subjects chose to be in the sanction-free institutions, they gradually switched until 90% chose the sanctioning institution in the last few periods of the session, where high contributions and high earnings prevailed. With high contributions, sanctioning itself was rarely needed.

Real societies can, through vote or revolution, choose their institutions. We capture part of this process in supplementary treatment T5 where subjects decided every five periods by majority vote whether to finance the public good through VACs or taxes. Subjects first experienced five periods with each of the two institutions T0 and T3. Then the initial endowments were reissued and one of the two institutions was chosen by a majority vote. The vote was repeated every five periods. We conducted four runs of this treatment for a total of 24 votes on choosing the institution.

The main result is that in 23 out of 24 majority votes subjects chose taxes over VACs.[18] Most of voting decisions were not close, with 7.6 of 10 votes for taxation on average, and a slight upward trend over time (7.3 in the first vote; 8.0 in the last). Only one decision (the third vote in run 3) favored VACs by 6:4 vote.

[18] This is nicely in line with e.g. Robbett (2014), who showed that when allowed to vote on taxes subjects in an experiment converged towards their respective optimum level.

One other vote in run 3 was a 5-5 tie; it was randomly resolved by computer in favor of taxes. We infer that with some experience and given the choice subjects understand that a system with perfectly enforced taxes makes them better off.

The four panels of Figure 7 present detailed results for four variables in T5 (stock of public good, tax rate, efficiency, and points earned from the public good) by period number. Besides the two thick dashed lines for equilibrium, two chain dotted lines for voluntary contribution economies have been added for comparison. Overall the results look similar to what we found in the other treatments, especially T3. Only in one run did the stock of the public good decline markedly from period 11 to 16. This is run 3, where subjects voted 6:4 for implementing VAC. The effect is visible in several panels of Figure 7: in the top left panel the stock of the public good dropped from 397 in period 10 to 314 after period 16. Afterwards, with taxes reinstated by 7:3 vote, and a comparatively high tax rate of 25 percent, the stock of the public good rose back to 385 by period 25.

Insert Figure 7 about here

In panel 2 (top right) tax rates (respectively the voluntary contributions rates) are displayed. Tax rates were at a similar level as in T3 and T4. The five periods with VACs in run 3 are highlighted with diamond markers and an unbroken line. Average contributions ranged from 5.1 to 9.8 percent – similar to the rates observed in T0, but markedly lower than under taxation regime. Efficiency, displayed in panel 3, bottom left, developed similarly to what we saw in T1 to T4. Finally, the bottom right panel shows the development of total production of private goods, which is similar to what we observed in T3.

5. Discussion and Concluding Remarks

Public goods decisions are made in rich institutional settings. States evolved over centuries by enforcing weights and measures, commercial codes, accounting rules, law and order, and tax collection. In this study we take it as a given that the structure of government is able to serve these functions.

We report on a novel laboratory experiment to explore the suitability of setting taxes through democratic voting to pay for public goods in a general equilibrium economy. We find that the four main treatments with finite horizon experimental economies sustain public goods between the finite- and infinite-horizon optima, and at 90 to 100 percent efficiency. Both the efficiency and the production of private goods are higher when the rate of taxation is determined by vote instead of being fixed at the GE optimum. Production of private goods is also not harmed by taxation. In the two treatments with voting, taxes remain at an intermediate level, converging neither to zero nor to 100%. Irrespective of whether we start at 50% or 100% of the optimum, the stock of the public good converges to the same level between the finite- and infinite-horizon optima. This holds also in the supplemental treatment T5 in which 23 out of 24 times subjects choose taxation over a voluntary contribution (VAC) regime by a majority vote. In all treatments except the one with VACs the ending stock of public goods exceeds the finite horizon optimum.

Our results suggest that the important social problem of financing public goods can be addressed, fairly and efficiency, by societies through taxes set by democratic vote. Dependence on voluntary contributions among large groups may be too unreliable a basis for providing services essential to their productivity, social cohesion, even survival. In the experiment the level of VACs is significantly lower than the level of tax contribution in any given period. While we know voluntary contribution to public goods rapidly deteriorates in many designs, it is important to establish the result in this design, particularly given the concavity of public goods production.

Still, voluntary contribution mechanisms have the inherent appeal of being decentralized, and thus insulated from tyranny. Taxation, representing centralized power and a centralized enforcement mechanism, has historical associations with oppression. Democratic government and taxation based on popular voting attempt to balance the consequences of centralization by fairness. Our experimental results suggest that such a reasonable balance is achievable for financing of public goods and services through democratic mechanisms. We find that the majority of subjects voted 23 times out of 24 to favor a system with taxes over VACs.

Subjects cut the tax rates marginally as the sessions progressed towards the end when the remaining stock of public good is worthless. They made up for lower taxation by saving more of their private goods, so that tax proceeds remained about the same regardless of whether taxes were set exogenously at the ex ante optimal level or set endogenously by a vote; and increased efficiency by doing so. This powerful result raises interesting questions for future research; e.g., is it the tax level itself or exogenous tax policy that induces suboptimal dis-saving?

As a limitation we note that our sample of experimental subjects (Austrian students) might be more receptive to taxation than other populations, especially in the U.S. We leave the answer to this question to a future study with cross-country subjects.

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Table 1: Experimental Design			
		Initial Level of Public Good	
Regimes for Public Good Provision		100 percent of Optimal	50 percent of Optimal
Voluntary anonymous contributions		**Treatment 0: 2 sessions***	
Taxation	Fixed at 21.5%	**Treatment 1: 4 sessions****	**Treatment 2:4 sessions**
	Tax rate set by vote	**Treatment 3: 6 sessions**	**Treatment 4: 6 sessions**
	Vote on system	**Treatment 5: 4 sessions*****	

*Voluntary contributions specified in units of money in one session and in percent of wealth in the other.
**Two of these four sessions permitted 0 inputs to private good production; all other sessions of the experiment required a minimum of 1 unit of input.
*** subjects decide by majority vote whether they implement a system with voluntary anonymous contributions or with taxes.

Table 2: Experimental Parameters and Design		
Parameters		
Number of Agents	n	10
Initial money endowment of agents	m	4,700
Initial pvt. good endowment of agents	a	217
Agents' pvt. Good production function	$f(k)$	$80*k^{0.25}$
Single period agent payoff	$u(x, G)$	$x + G/4$
Session agent payoff		Sum of period-wise payoffs
Initial government public good endow.	G	427 (T1, T3) or 213.5 (T2, T4)
Initial government money endowment	M	13,000
Government's public good prod. function	$F(k)$	$2*k^{0.5}$
Natural rate of discount	β	1
Depreciation rate (per period)	η	0.1
Terminal value of public good		0
Session termination	Announced: random btw. periods 25 and 30 Actual: always ended after vote in period 26	
Equilibrium Outcomes		
Price of private goods	p	27.67
Per capita production of pvt. good		217
Per capita purchase of pvt. good		170
Per capita consumption of pvt. good		116 (68.27% of 170)
Per capita pvt. Good into production		54 (31.73% of 170)
Production of public good		42.7

Table 3: Summary of Hypotheses and Tests

Hypothesis	Variable	Null Alternative	T1 vs. T0	T2 vs. T0	T3 vs. T0	T4 vs. T0	T1 vs. T2	T3 vs. T4	T1 vs. T3	T2 vs. T4	T3	T4	T5
Ia	Tax rates	ETR = Equil. ETR < Equil.									Reject. p<0.01	Reject. p<0.01	
Ib	Tax rates	ETR = 0 ETR > 0									Reject. p<0.01	Reject. p<0.01	
II	Provision for PG	ETR = VAC ETR > VAC	Reject. p<0.01	Reject. p<0.01	Reject. p<0.01	Reject. p<0.01							
IIIa	Final Level of PG	HIE =LIE					Not rej. p=0.25	Not rej. p=0.43					
IIIb	Final Level of PG	ETR = FTR							Not rej. p=0.29	Not rej. p=0.83			
IIIc	Final Level of PG	ETR = VAC ETR > VAC	Reject. p=0.06		Reject. p=0.05								
IIId	Var of Level of PG								Not rej. p=0.45	Reject. p<0.01			
IVa	Efficiency	HIE =LIE HIE > LIE					Not rej. p=1.00	Reject. p=0.02					
IVb	Efficiency	ETR = FTR ETR < FTR							Reject. p=0.01	Reject. p=0.09			
IVc	Efficiency	Tax = VAC Tax > VAC	Not rej. p=0.64		Reject. p=0.05								
Va	Pvt. Good Production	ETR = FTR ETR <> FTR							Reject. p<0.01	Reject. p=0.02			
Vb	Pvt. Good Production	Tax = VAC Tax <> VAC	Not rej. p=0.36	Reject. p=0.06	Reject. p=0.05	Not rej. p=0.18							
VIa	% Earn from PG	HIE =LIE HIE > LIE					Reject. p=0.02	Not rej. p=0.87					
VIb	% Earn from PG	ETR = FTR ETR < FTR							Reject. p=0.01	Not rej. p=0.39			
VIc	% Earn from PG	Tax = VAC Tax > VAC	Reject. p=0.06	Reject. p=0.06	Reject. p=0.05	Reject. p=0.05							
VII	VAC or Tax by vote	Tax = VAC Tax > VAC											Rej. at p<0.01

ETR = Endogenously determined tax rate

VAC =Voluntary anonymous contributions
HIE/LIE = High/Low initial endowment of public good
FTR = fixed (at optimum level) tax rate
Var Level of PG = Variation of final level of public good across sessions of the same treatment

Figure 1: Time line of a period in the experiment

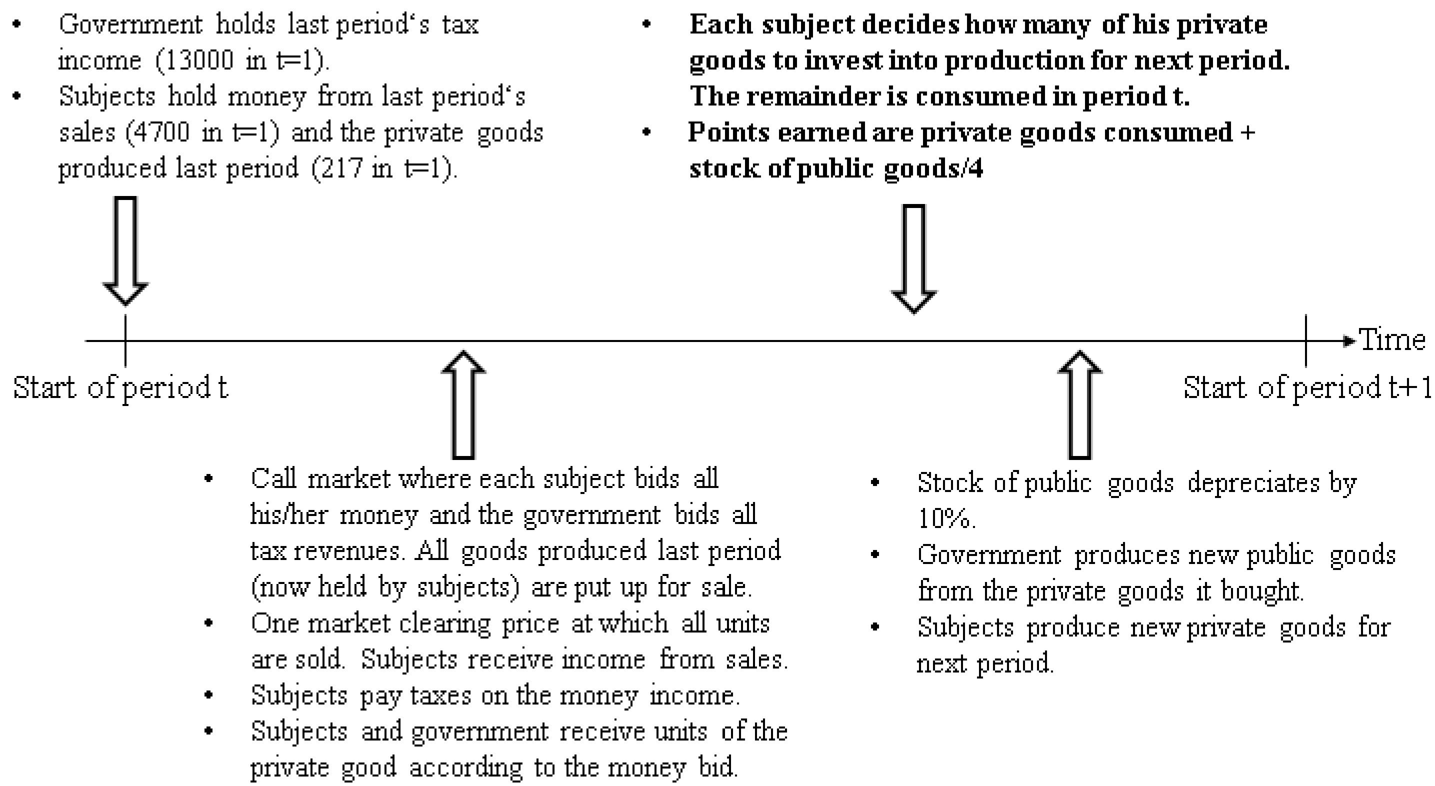
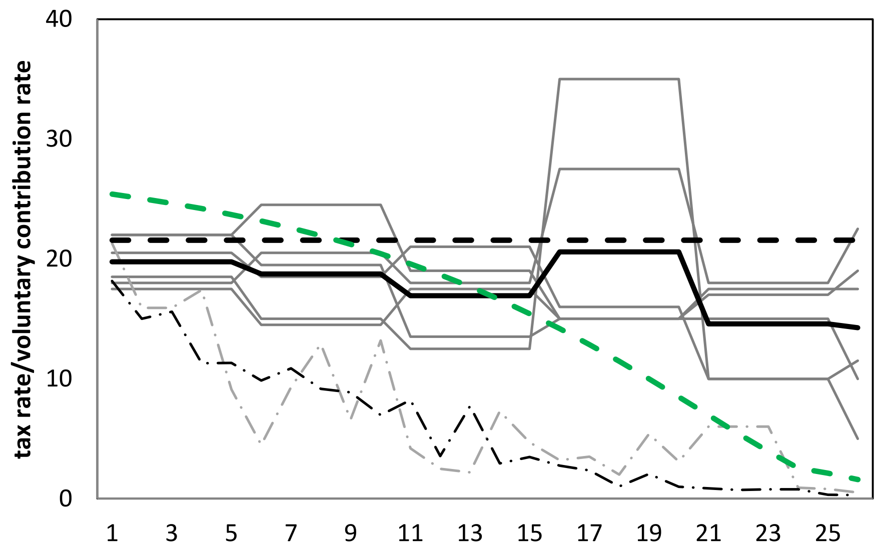


Figure 2: Evolution of Tax Rates over Time

individual tax runs — Average (tax runs) — T0 voluntary % — T0 voluntary $ — GE(Infinite) — GE(Finite)

T1: Tax rate fixed, starting level of public good at optimum	T2: Tax rate fixed, starting level of public good below optimum
Tax Rate fixed at 21.5%	Tax Rate fixed at 21.5%

T3: Tax rate endogenous, starting level of public good at optimum



T4: Tax rate endogenous, starting level of public good below optimum

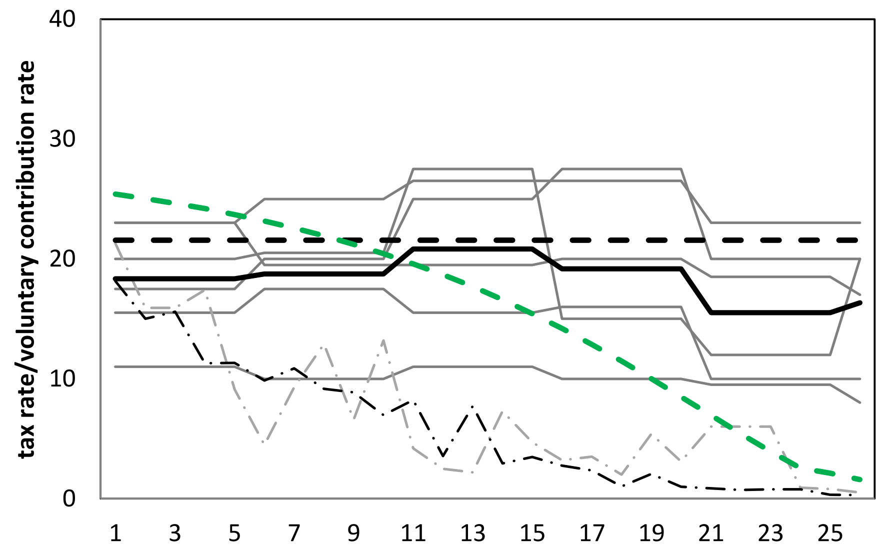


Figure 3: Stock of Public Good in Economies Grouped by Four Types of Sessions

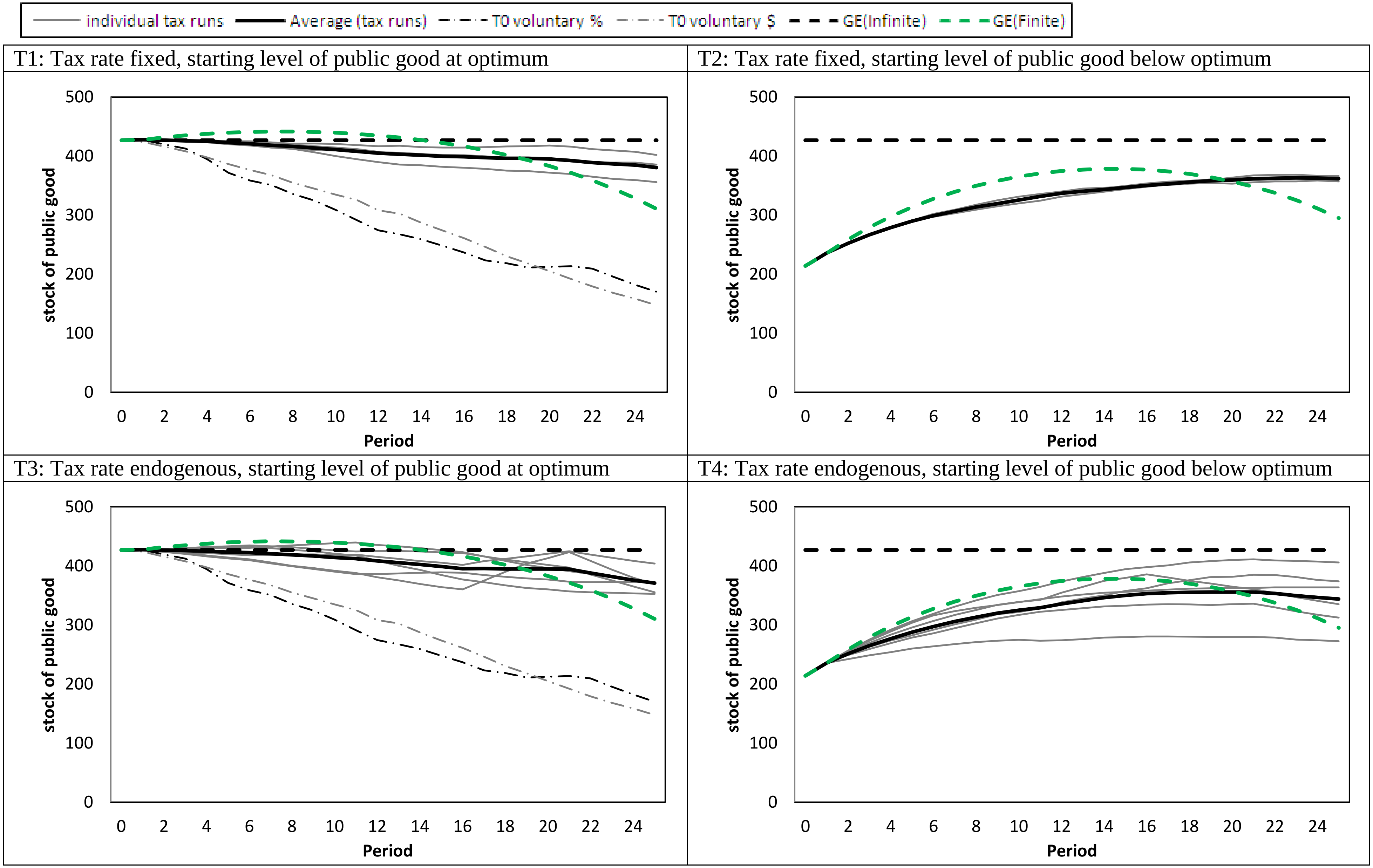


Figure 4: Efficiency of the Economies with GE(Infinite) being the Benchmark

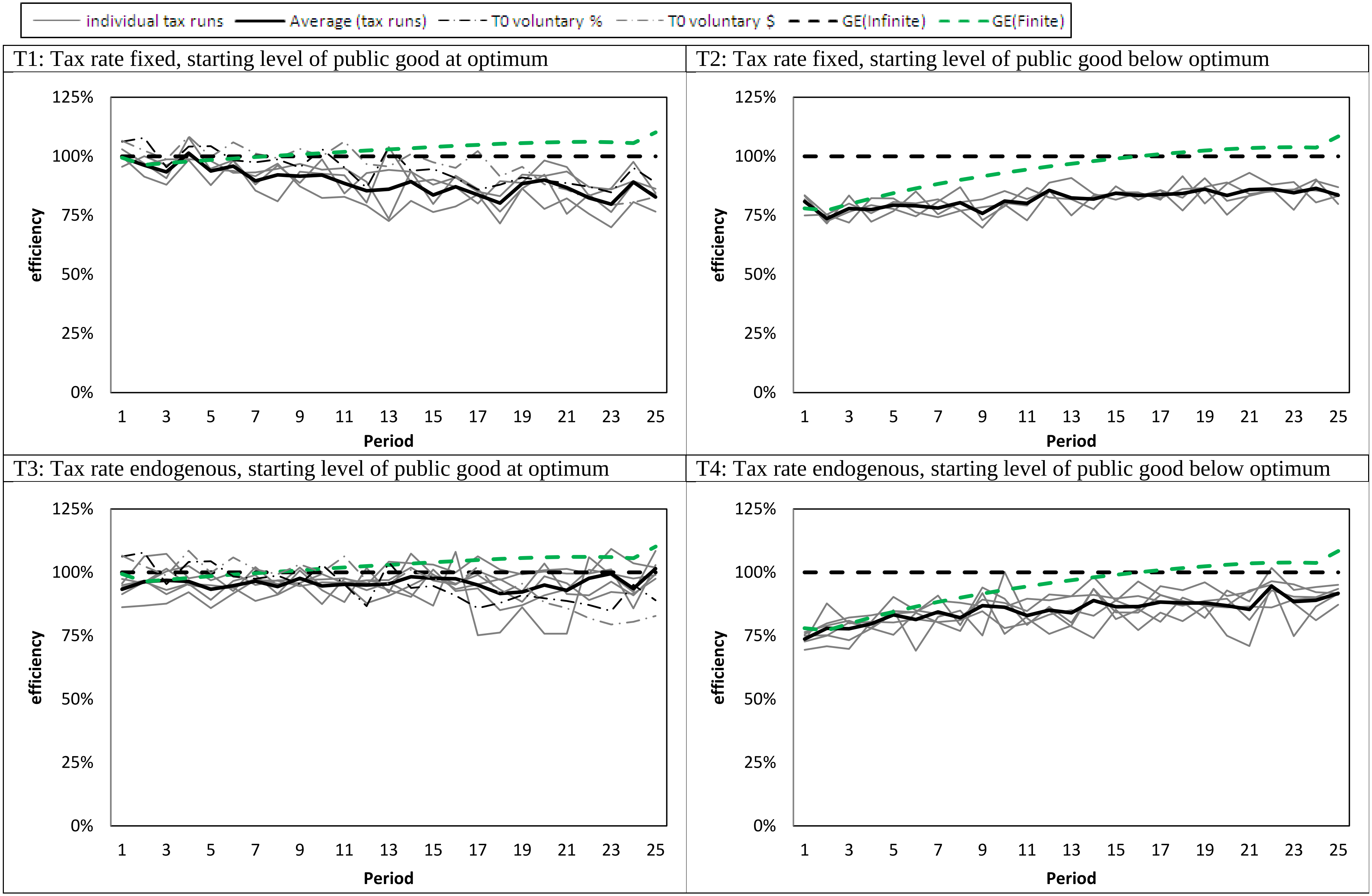


Figure 5: Total Production of Private Goods in the Economies

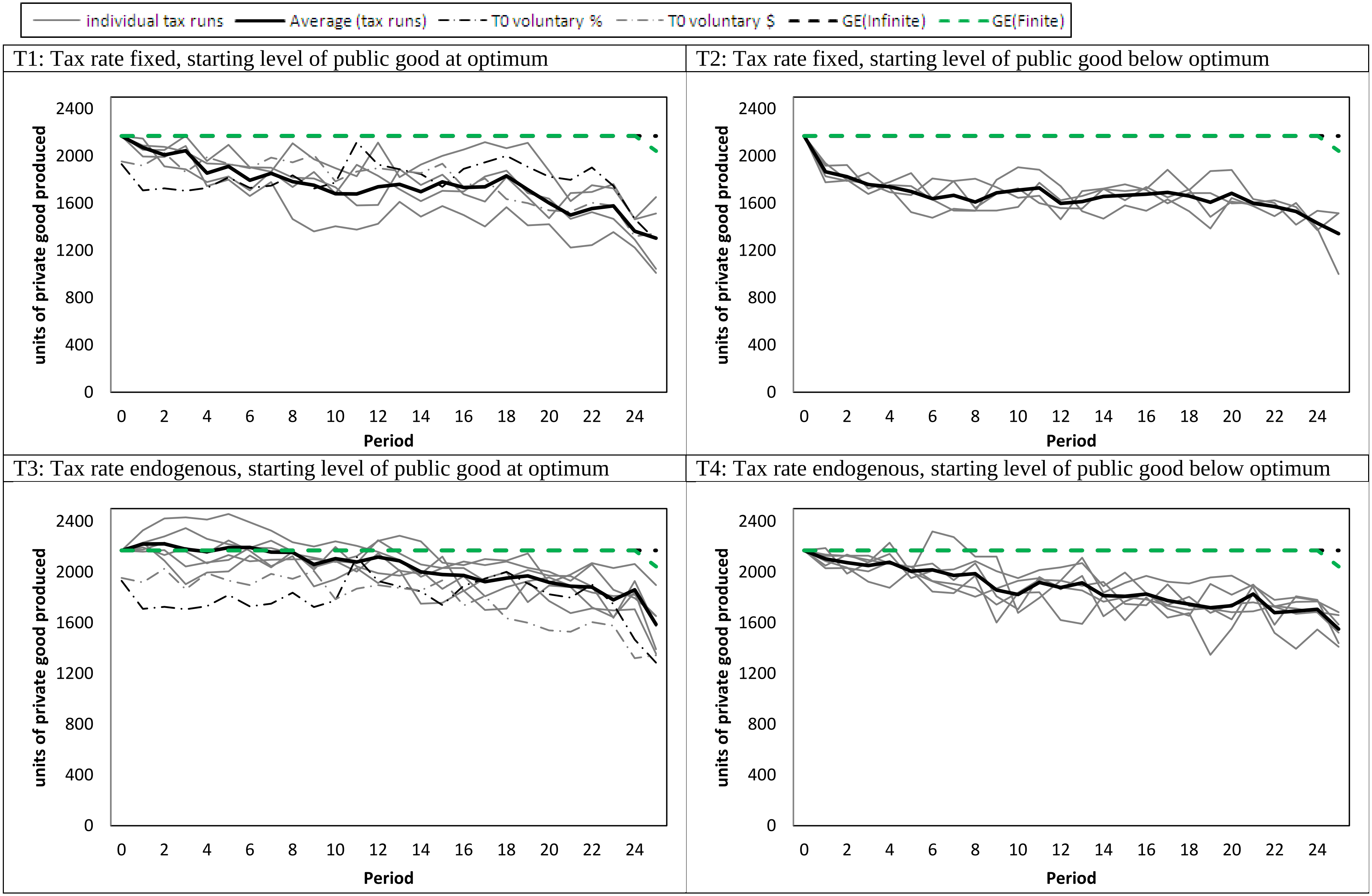


Figure 6: Percentage of Utility Earned from the Public Good (rather than from Consumption of Private Goods)

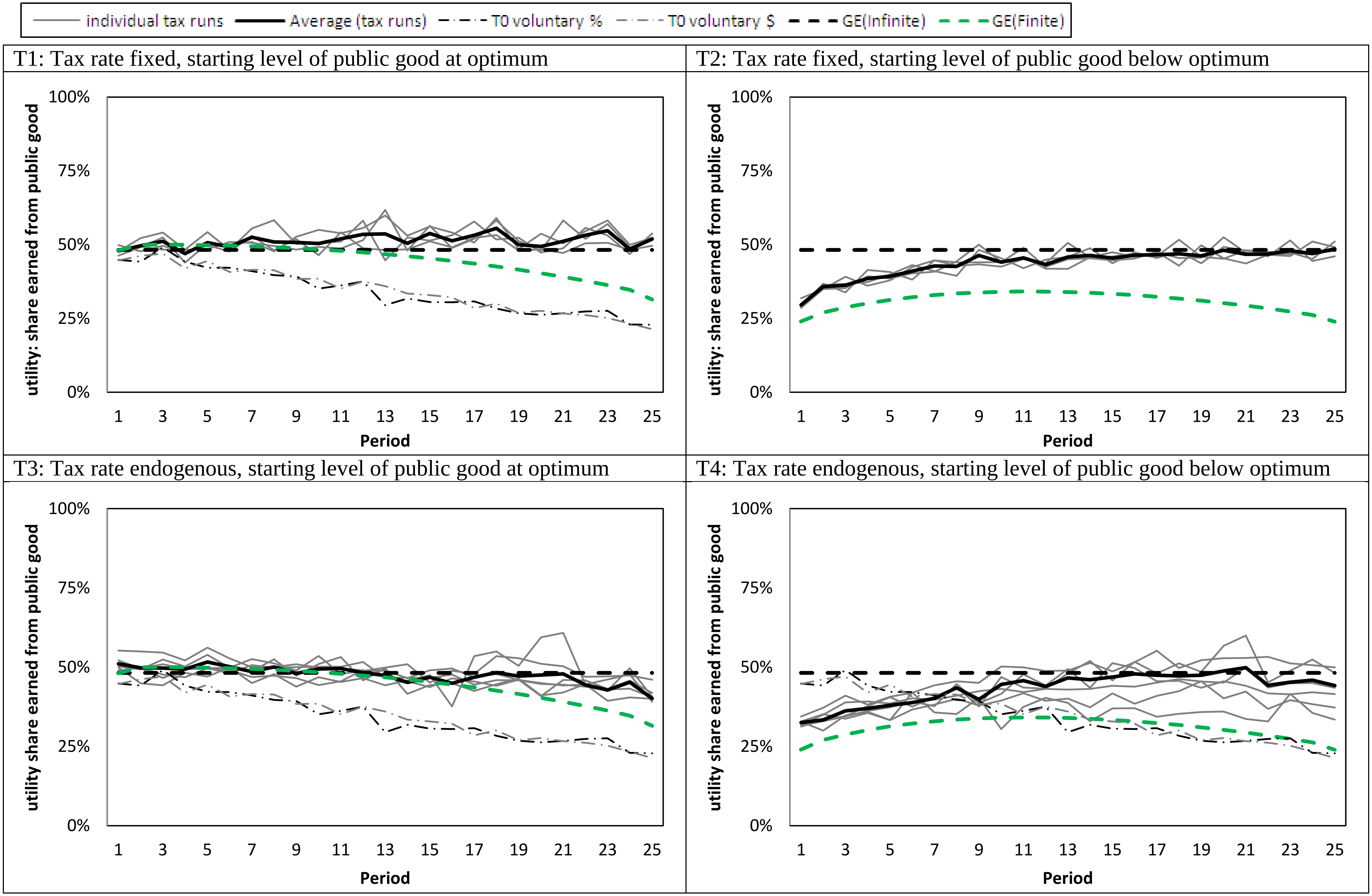
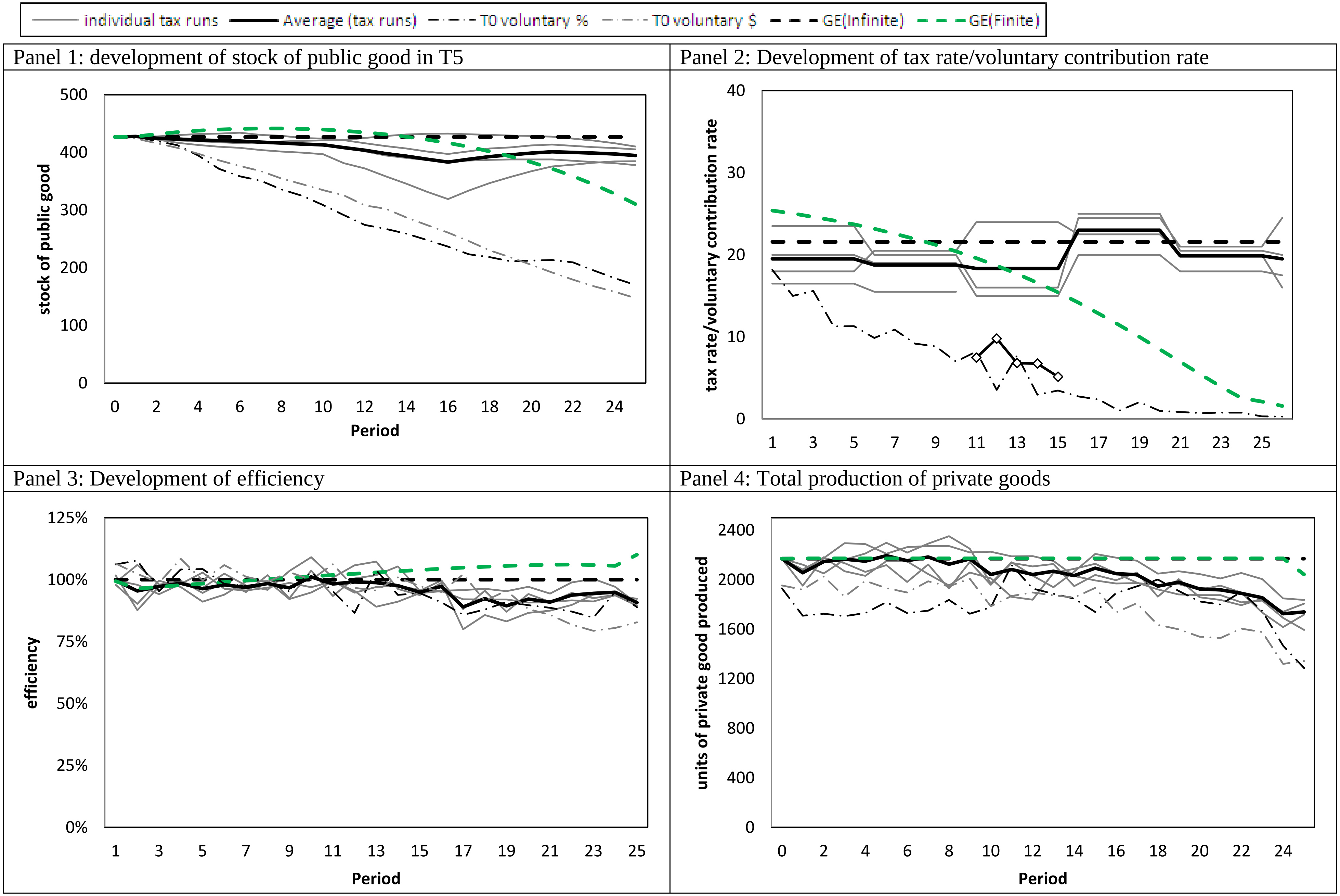


Figure 7: Data for T5 where subjects voted on the system to be implemented. Notation follows that of Figures 2 to 6.



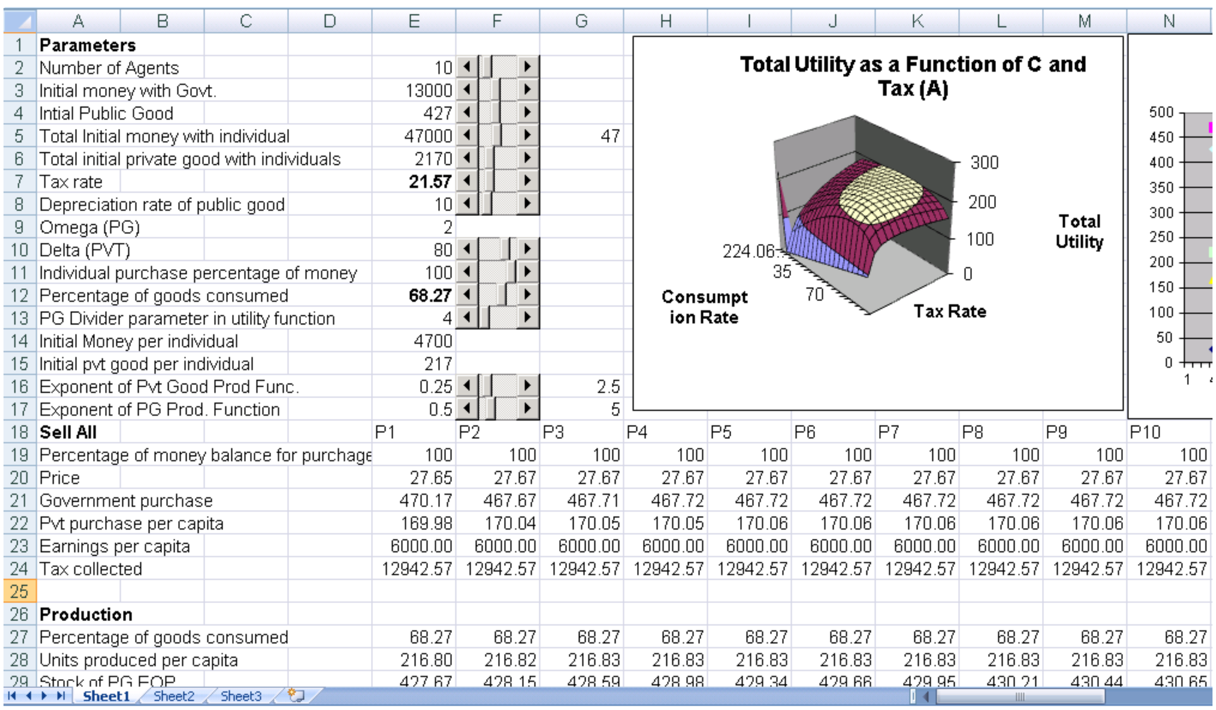
APPENDIX A – explanation of online material

As supporting material for this paper we provide two MS EXCEL worksheets, one for infinite horizon, one for a finite horizon of 30 periods. In both worksheets all relevant input variables can be varied in cells E2 to E17. The respective notation can be found in cells A2 to A17. Especially noteworthy in the infinite horizon setting are the tax rate (E7) and the consumption rate (E12) as these are the two variables for which we optimized by use of the solver function of MS EXCEL.

In rows 19 to 24 (22 to 28 in the finite setting) the sell-all market is modeled, with period 1 in column E, and subsequent periods to the right, up to period 20 in the infinite setting and period 30 in the finite setting. Right below, are the productions of private and public goods, again from period 1 (column E) to period 20 (30 in the finite setting).

Several graphs from Columns H to AD illustrate the results and their sensitivity to variations in the input variables. Figures 7 and 8 give screenshots of part of the respective excel sheets, which would be continued in further rows down and further columns to the right.

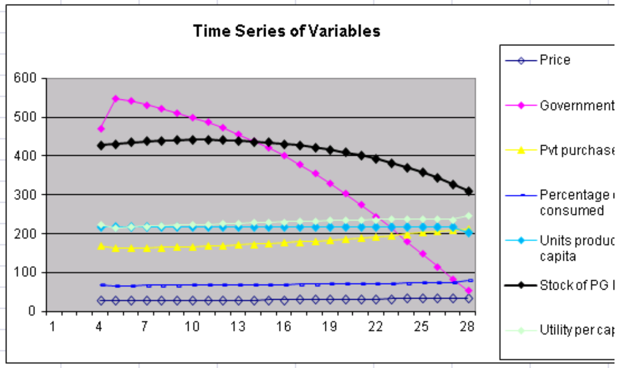
Figure 7: MS EXCEL screenshot for model with infinite horizon. The Graph in the top rows of columns I to N shows total utility as a function of consumption rate (E12) and tax rate (E7).



	A	E	F	G	H	I	J	K	L	M	N
1	**Parameters**										
2	Number of Agents	10									
3	Initial money with Govt.	13000									
4	Intial Public Good	427									
5	Total Initial money with individual	47000		47							
6	Total initial private good with individuals	2170									
7	Tax rate	**21.57**									
8	Depreciation rate of public good	10									
9	Omega (PG)	2									
10	Delta (PVT)	80									
11	Individual purchase percentage of money	100									
12	Percentage of goods consumed	**68.27**									
13	PG Divider parameter in utility function	4									
14	Initial Money per individual	4700									
15	Initial pvt good per individual	217									
16	Exponent of Pvt Good Prod Func.	0.25		2.5							
17	Exponent of PG Prod. Function	0.5		5							
18	**Sell All**	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
19	Percentage of money balance for purchage	100	100	100	100	100	100	100	100	100	100
20	Price	27.65	27.67	27.67	27.67	27.67	27.67	27.67	27.67	27.67	27.67
21	Government purchase	470.17	467.67	467.71	467.72	467.72	467.72	467.72	467.72	467.72	467.72
22	Pvt purchase per capita	169.98	170.04	170.05	170.05	170.06	170.06	170.06	170.06	170.06	170.06
23	Earnings per capita	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00
24	Tax collected	12942.57	12942.57	12942.57	12942.57	12942.57	12942.57	12942.57	12942.57	12942.57	12942.57
25											
26	**Production**										
27	Percentage of goods consumed	68.27	68.27	68.27	68.27	68.27	68.27	68.27	68.27	68.27	68.27
28	Units produced per capita	216.80	216.82	216.83	216.83	216.83	216.83	216.83	216.83	216.83	216.83
29	Stock of PG EOP	427.67	428.15	428.59	428.98	429.34	429.66	429.95	430.21	430.44	430.65

Figure 8: MS EXCEL screenshot for model with finite horizon of 30 periods. Here the tax rate (E7) and consumption rate (E12) are no longer fixed for several periods, but instead change from period to period. The respective values are displayed in rows 19 and 20.

	A	E	F	G
1	**Parameters**			
2	Number of Agents	10		
3	Initial money with Govt.	13000		
4	Intial Public Good	427		
5	Total Initial money with individual	47000		47
6	Total initial private good with individuals	2170		
7	Tax rate	**see row 22**		
8	Depreciation rate of public good	10		
9	Omega (PG)	2		
10	Delta (PVT)	80		
11	Individual purchase percentage of money	100		
12	Percentage of goods consumed	**see row 23**		
13	PG Divider parameter in utility function	4		
14	Initial Money per individual	4700		
15	Initial pvt good per individual	217		
16	Exponent of Pvt Good Prod Func.	0.25		2.5
17	Exponent of PG Prod. Function	0.5		5



	A	E	F	G	H	I	J	K	L	M	N	O
18												
19	Tax rate	25.35	25.02	24.62	24.18	23.69	23.15	22.56	21.91	21.20	20.43	19.58
20	percentage of goods consumed	68.05	66.94	67.14	67.36	67.60	67.86	68.14	68.43	68.75	69.09	69.45
21												
22	**Sell All**	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11
23	Percentage of money balance for purchage	100	100	100	100	100	100	100	100	100	100	100
24	Price	27.65	27.72	27.83	27.95	28.09	28.24	28.41	28.59	28.80	29.02	29.26
25	Government purchase	470.17	548.72	541.12	532.28	522.48	511.67	499.80	486.78	472.52	456.93	439.91
26	Pvt purchase per capita	169.98	162.30	163.04	163.94	164.91	165.99	167.18	168.48	169.91	171.47	173.17
27	Earnings per capita	6000.00	6020.00	6044.05	6070.72	6100.37	6133.15	6169.36	6209.30	6253.34	6301.82	6355.12
28	Tax collected	15210.73	15060.78	14879.47	14677.26	14451.02	14199.10	13918.69	13606.78	13259.78	12874.01	12445.35

Sheet1 Sheet2 Sheet3

APPENDIX B: Instructions

Dear participant: Welcome to the experiment. Please do not talk to any other subject for the duration of the experiment.

You are one of ten subjects populating a small economy with money and two kinds of goods: one private and one public good. As subjects, you will produce, sell, buy, and consume the private good. The government (played by the experimenter) will tax the income of subjects (from sale of the private good) and use the proceeds to buy some of the private good, to be used to produce the public good. The tax rate will be either fixed, or determined by the vote of the ten subjects once every five periods. Your earnings for each period depend on the quantity of private good you consume, and the quantity of the public good provided by the government for benefit of all in that period.

Money and Goods

There is money and two kinds of goods in the economy:

- A private good produced, sold, bought and consumed by the participating subjects; some the private good is also bought by the government and used to produce the public good.
- The public good (e.g., a public facility) which depreciates at the rate of 10 percent per round. The government uses tax collected from subjects to replenish the depreciating stock of public good.

In round 1 each subject starts with 4,700 units of money and 217 units of the private good. The government starts with 13,000 units of money and 427 (*213.5 in half of the runs*) units of the public good.

At the beginning of each round, all private good produced in (and carried over from) the preceding round) is sold in a market. Thus, the initial private good endowment of 217 units in the hands of each subject (for a total of 2,170) is sold at the start of round 1.

Money serves only a means of exchange in this economy, but it has no role in savings, etc. An amount of money is given to you at the beginning of the session, and any balance left over at the end of the session has no value to you. Each round all money you have (either initial endowment or earned from sale of goods the round before) is spent for the purchase of goods at the start of each round. No borrowing is possible.

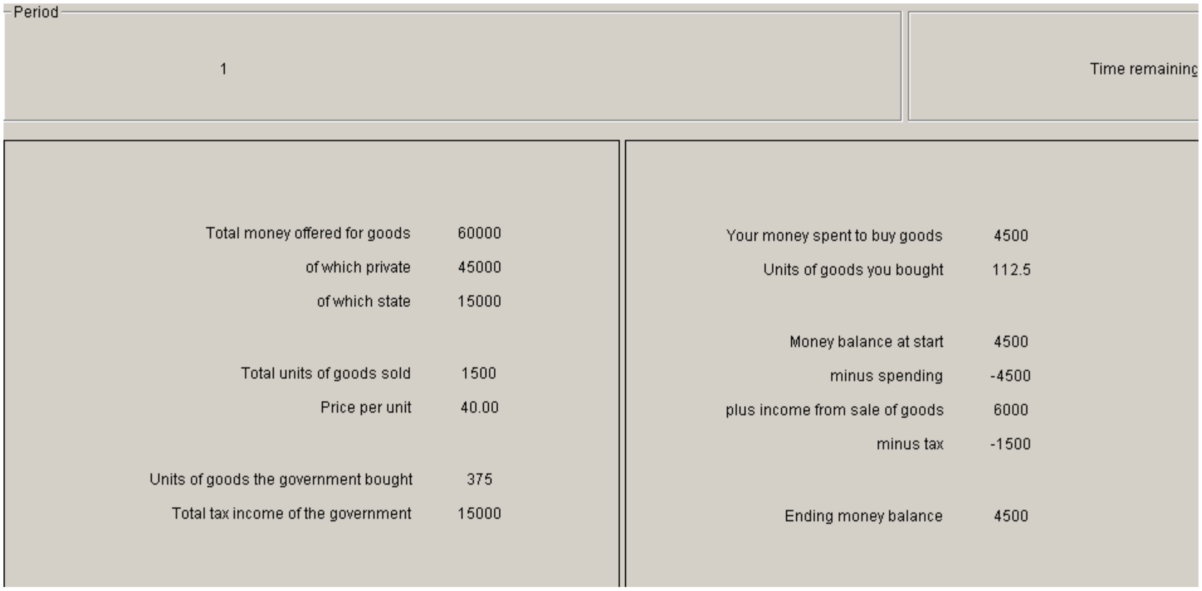
At the start of a period all money held by the government and individuals is tendered to buy units of the private good. In the first period 2,170 units are sold for a total of 60,000 units of money.

Total agent and government bids in money = 60,000/2,170 (total number of units of private good) = 27.65. These numbers will change in subsequent rounds.

Each individual buys 170 units and earns 217*27.65=6,000 units of money. Your first decision is how many of these 170 units you invest into production for the next period, with the remainder being consumed this period. Your money income (6,000 in the first period) is taxed by the government at a rate set by all subjects through a vote (see details below).

On the left side of the Screen 2 you learn the total money bid for private good, the resulting price, the units bought by the government, and government's tax revenue (all of which is spent to buy private goods in the following round). On the right side of Screen 2 you see how many units you bought, your spending, income, tax, and the initial and final money balances (the latter to be carried over to the following round).

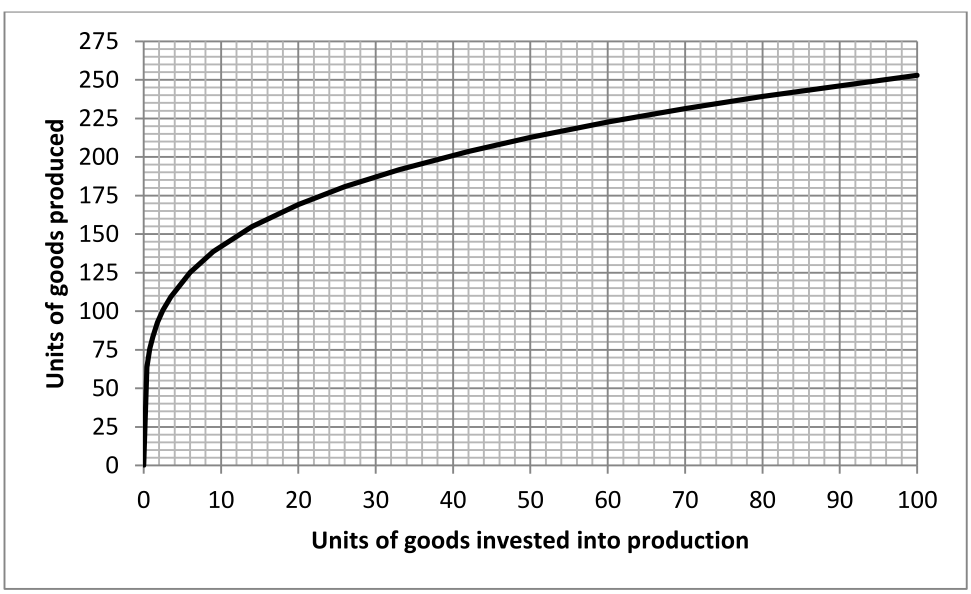
Screen 2



Out of the units of private good you bought, you have to decide on how many you wish to consume, and how many you wish to invest to produce private goods to be sold during the next round. The following equation and chart show the relationship between the units you invest and the units produced:

UNITS OF THE PRIVATE GOOD PRODUCED = 80*(UNITS INVESTED)$^{0.25}$.

Note, for example, that investing 1 unit produces 80 units; investing 40 units produces 201.19 units.



Public Good

The government starts with a stock of 427 units of the public good. This stock depreciates by 10% each round, like, for example, roads deteriorate. To maintain or upgrade the public good the government taxes the subjects' income (from sales of goods) at the selected rate. All tax receipts are used to buy the private good and all private goods are used to produce new units of the public good according to the following function:

UNITS OF THE PUBLIC GOOD PRODUCED = 2*(UNITS OF PRIVATE GOOD INVESTED)$^{0.5}$.

Taxes

All individual income (proceeds from sale of private good) will be taxed at a flat tax rate (which is either fixed by the experimenter in advance, or is set by the vote of ten subjects). In the latter case, every five rounds (i.e., at the beginnings of rounds 1, 6, 11, 16, etc.) each subject is asked to submit his/her suggested percent rate of taxation to be applicable to all ten subjects. You are free to suggest any integer number between zero (no tax) and 100 (everything taken by the government) as the percent tax rate. The computer collects the suggested tax rates from the ten subjects, sorts them from highest to lowest, and sets the median (average of the 5th and the 6th suggested rates) as the tax rate for all subjects. The selected tax rate is announced, and it remains in effect for five rounds until the next tax rate is determined though another vote. (*In half of the treatments the tax rate was fixed at 21.5. percent and no vote was carried out*)

Points earned

The points you earn in each round are calculated as:

POINTS = CONSUMPTION OF PRIVATE GOOD + PUBLIC GOOD/4.

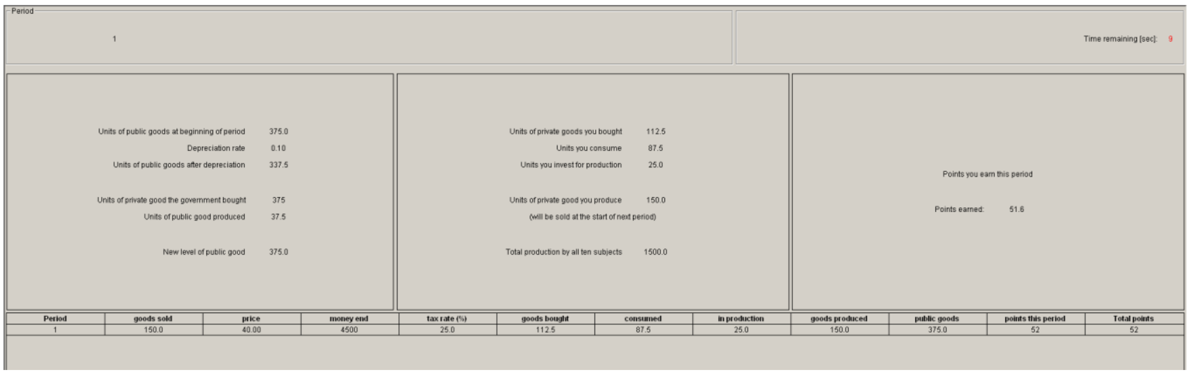
For example, if you consume 60 units of private good and the government provides 200 units of public good, you earn 60 + 200/4 = 110 points in that period. Both higher private good consumption as well as higher stock of the public good increase your earnings. Chart 1 and Table 1 show the number of points resulting from various combinations of private good consumption and public good provision by government.

(Insert Chart 1)

History screen:

After all subjects have entered their consumption/investment decisions, computer carries out all the calculations, and a history screen provides a round-by-round overview of the results (the accounting of public goods on the left, your consumption and production of goods in the middle, the points you earn during the round on the right, and the summary of the round at the bottom.

History Screen



Final payment:

There is 1/6 chance that the experiment will last for 25, 26, 27, 28, 29, or 30 rounds. The actual number of rounds in the session will be determined randomly before we start, but will not be announced to you until the session ends.

The points earned during all rounds are added up (column "Total points" in the History Screen). Your take-home payment in euro is TOTAL POINTS / 200. For example, if the experiment ends in round 28 and you earned a total of 3,000 points during these 28 rounds, your take-home payment is 3,000/200 = 15 Euros.

(Appendix C: not for publication; inserted as a separate PDF file for editors. The source Karatzas et al. 2006 is referenced in Section 2 of the paper and included in the list of references).