AN ECONOMY WITH PERSONAL CURRENCY: THEORY AND EXPERIMENTAL EVIDENCE

By

Martin Angerer, Juergen Huber, Martin Shubik, and Shyam Sunder

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COWLES FOUNDATION FOR RESEARCH IN ECONOMICS
YALE UNIVERSITY
Box 208281
New Haven, Connecticut 06520-8281

http://cowles.econ.yale.edu/

An Economy with Personal Currency: Theory and Experimental Evidence

Martin Angerer and Juergen Huber, University of Innsbruck

Martin Shubik and Shyam Sunder[1], Yale University

Abstract

Is personal currency issued by participants sufficient to operate an economy efficiently, with no outside or government money? Sahi and Yao (1989) and Sorin (1996) constructed a strategic market game to prove that this is possible. We conduct an experimental game in which each agent issues her personal IOUs, and a costless efficient clearinghouse adjusts the exchange rates among them so the markets always clear. The results suggest that if the information system and clearing are so good as to preclude moral hazard, any form of information asymmetry, and need for trust, the economy operates efficiently at any price level without government money. These conditions cannot reasonably be expected to hold in natural settings. In a second set of treatments when agents have the option of not delivering on their promises, a high enough penalty for non-delivery is necessary to ensure an efficient market; a lower penalty leads to inefficient, even collapsing, markets due to moral hazard.

Keywords: strategic market games, government and individual money, efficiency, experimental gaming

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Email: martin.angerer@uibk.ac.at, juergen.huber@uibk.ac.at, martin.shubik@yale.edu, and shyam.sunder@yale.edu.

1. INTRODUCTION

Whether private money alone is sufficient to run an economy efficiently has been a matter of debate for many years. The proponents of an economy without government money have argued that if all individuals and institutions were to issue their own debt as a means of payment, the market would sort out their reputations and risk associated with accepting such paper from different issuers (for example, see Black 1970). Indeed, some customs and practices in markets for money and the language of banking seem to be consistent with this view. In the City of London, the rates of interest charged in dealings with "prime" and "lesser" names are different. In the free banking era in the United States, there was an active market for discounting bills issued by hundreds of banks. In this paper we report the results of a laboratory experiment and find that the economy can be run efficiently on individual credit alone under stringent but unrealistic conditions for clearing and delivery. Relaxing the delivery conditions causes the efficiency to drop sharply unless defaults on delivery are punished.

Formal modeling of monetary economies as a strategic market game has led to the conclusion that government fiat money is not necessary if there is perfect clearing and no default (Sahi and Yao, 1989, and Sorin, 1996). Like the Modigliani-Miller's (1958) observation about the neutrality of the cost of capital with respect to leverage, this result is valid under conditions that are clearly counter-factual. Given exogenous uncertainty and dispersed and imperfect information, a smoothly functioning economy using individually created credit lines with no default appears to be institutionally difficult to obtain, even if it were logically possible. The problem lies not in the usual economic equilibrium models but in the information and evaluation network. Process dynamics, trust, and evaluation are core issues in the functioning of the financial system, and these are not present in the Black or Modigliani-Miller observations, neither are they modeled in our current experiment.

There is another fact of life in favor of government money that goes against the formal results: No bank—much less an individual—can match the visibility of the government which is known to essentially everyone. Historically, at least since the Lydians around 630 BC, governments have been involved in issuing money.

The use of government money initially became accepted because of the government's reputation and ability to enforce the rules of the game quickly and uniformly. Additionally, it expedited and simplified taxation, and as an unintended consequence, handed government an instrument to choose heretofore inaccessible policy options (e.g., to finance war) and to control the economy in other ways. Private issue of money weakens the power of government arising from its control of money.

The acceptance of government as well as individual IOUs as money requires an expectation that there are plenty of others who will accept the instrument as a means of payment. Since there may be little recourse to nonperformance on IOUs issued by government or individuals who go bankrupt, accepting such money involves an element of trust. The universal acceptability of money issued by stable and trustworthy governments may exceed the acceptability of instruments issued by their nearest competition—the big banks.[2]

[2] This is amply illustrated by the 2007-9 financial crisis occurring at the time of this writing.

Gold, in spite of its unwieldiness, has longevity and direct commodity value that makes it more trustworthy than government-issued paper money, but government money may be more trustworthy and generally acceptable than paper issued by banks. Most individuals, being virtually unknown to the public at large, would find it difficult to have their IOUs accepted as a means of exchange.

In international trade, many countries issue their own respective means of payment. In an international trade context, each agent is a long-lived bureaucracy with a reputation and engages in trades that are settled with considerable time lags. Formally the mathematics of the "personal IOUs" game is an abstraction for the study of the statics of the n-nation, n-currency competitive international trade model, but for exploring the dynamics of this phenomenon it is probably too stripped of the context.

There are one qualitative and three quantitative approaches available to adduce empirical evidence. The first involves a historical and journalistic approach enhanced with some raw or slightly processed numerical data woven into a plausible argument that the theory fits the facts. The other three are more quantitative and call for (i) econometric methods applied to a statistical representation of some aspects of the ongoing economy, (ii) experimental gaming with reward-motivated human agents in a laboratory representation of the economy, or (iii) simulation with a computer model of the economy populated by artificial agents.

We employ a two-pronged approach to examine the theory of money. The first step calls for game theoretic modeling of the economy in order to be specific about both the model (the rules of the game, information conditions and state space) and the solution concept considered. We select two solution concepts: moves chosen by economic agents with rational expectations and moves selected by agents with minimal intelligence. These solutions provide behavioral upper and lower bounds for what individual agents in the economy might do, and we expect the behavior of human subjects in naturally occurring and laboratory economies to fall within these bounds.

The second step in our work is the use of experimental gaming to compare and contrast the behavior of the experimental economy with the outcomes suggested by the two considered solutions of the game theoretic models.

A firm foundation for a viable theory of money and financial institutions calls for formulation, investigation and sensitivity analysis of many special models. Following our modeling of the simplest of structures, many variants of the model call for investigation. We select two sets of experiments. The first shows that under extremely strong conditions on a market clearing mechanisms government money is not needed. The second shows that as soon as one considers deviations such as a possibility of strategic failure to deliver on one's promises, efficient individual issue of credit cannot be sustained without considerable enforcement.

We are well aware that development of reputation is a key to a pure credit economy. It is extremely difficult to develop *in vitro* experiments to catch the long term *in vivo* aspects of the development of reputation and trust and we have left out this important aspect money for future research.

Until the work of Sahi and Yao (1989) and Sorin (1996) there was no known mathematical model and proof of the existence of an equilibrium with individual issue of a personal credit money. These results can be easily extended to games with a finite horizon and given terminal conditions. This is what we do here.

We follow the more or less standard approach to experimentation where one attempts to simplify and control as much as necessary. In particular the use of gaming forces us to specify precisely oft-ignored institutional features such as bid size, number of individuals in a market, discrete versus continuous time and what is meant by a static or dynamic model.

To understand money, not only do we need to distinguish between static and dynamic equilibria, but also be precise about what is meant by dynamic disequilibrium.[3] In the work presented here the institutions provide constraints (and hence guidance) on the motion of financial instruments. The selection of terminal conditions introduces a simplified form of expectations; like rational expectations this permits the prediction of the dynamic equilibrium.

In the laboratory, we used a computer to perform two tasks; (1) to calculate the exchange rates among the units of personal credit issued by individual agents, and (2) to function as a clearinghouse. In Treatment 1 the computer did not permit individuals to renege or to go bankrupt, and thus from developing a bad reputation. In Treatment 2 subjects were not prevented from reneging on their promises and thus a market breakdown became a possibility. The computer helped us cleanse the lab economy of the frictional and informational issues so we could examine the ‘personal IOUs’ model in absence of such alternative explanations for the prevalence of government money.

Briefly, in absence of moral hazard this mechanism yields efficiencies as high or higher than the three market games studied in Huber et al. (2010), confirming that an economy with individual credit is logically as well as behaviorally feasible and efficient. We show that a key claim in competitive market theory, that government money is not needed to achieve efficient exchange, can be established experimentally as well as theoretically. However, when reneging on promised delivery is possible, markets are less efficient and may even break down, depending on the penalty for non-delivery. Thus, efficiency appears to depend on ideal contract enforcement, credit evaluation and clearing arrangements in the economy. These are implicit in the model as well as treatment 1 of the laboratory set up, but not in treatment 2, where failure to deliver is possible.

Our basic approach is minimalist, while at the same time it acknowledges that there are dozens, if not hundreds of experiments that need to be done in the development of economic understanding. Here we make no pretence at great generality. We specifically tackle one basic problem and having answered it we consider some extensions. Sahi and Yao (1991) and Sorin (1995) were able to mathematize the idea of every individual generating their own credit in a decentralized manner but utilizing a globally centralized clearinghouse to calculate exchange rates. This contrast with the trading post model of a strategic market game where the sole use of a commodity money[4] or a government money does not require centralized clearing as every market clears by itself (see treatments 1, 2 and 3 in Huber, et. al. 2010). We show that relatively unsophisticated students and minimal intelligence players will perform fairly closely in accord with the theory. When failure to deliver is not possible (in treatment 1), or the

[3] A formal definition of disequilibrium poses many difficulties as was indicated by the perceptive article of Ragnaar Frisch 1936. We do not attempt a coverage of this point here.

[4] The money could be a direct consumption good such as bags of tea, bales of tobacco, cigarettes or bars of salt (see Dubey, Geanakoplos and Shubik, 2003). The distinction between the asset and the flow of services obtained from the asset is discussed there.

penalty for such failure is sufficiently high (treatment 2a). However, with low or zero penalty the market tends to breaks down (treatments 2b and 2c). When the number of subjects is reduced from ten (5+5) to four (2+2), oligopolistic effects play a much larger role and as a result efficiency is significantly lower.

In Section 2 we discuss the model, touching on problems such as the multiplicity of equilibria and the selection of a numeraire. Section 3 gives the experimental setup and Section 4 the results. Section 5 presents the design and results for economies with moral hazard, and Section 6 contains our concluding remarks.

2. The Model

A strategic market is a game in strategic or extensive form, usually representing an exchange or exchange and production economy, and is closely related to the general equilibrium model of an exchange or exchange and production economy. A basic difference between a strategic market game and general equilibrium model is that the former provides an explicit mechanism for price formation, the latter does not. The game serves as the basis for a playable experiment with full process details given.

There are two basic versions of the strategic market game: the "trading post" and the "windows" model. The trading post model is completely decentralized. Imagine *m* trading posts, one for each good. The manager of each trading post deals only in one good. She collects the consignments of that good offered for sale, and the money being offered to buy that good, calculates the clearing price and allocations, and transfers the traded goods and money among the traders. In contrast the windows model requires a centralized agency that may be interpreted as a general clearing house that gathers the promises for the consignments of all goods and bids of personal money or IOU notes for all goods and calculates a set of exchange rates that clear all markets among all of the individual credit lines issued by every trader. Thus in order to balance all books the clearing house also has to calculate the appropriate exchange rates. We sketch the general formal model as follows: Consider a set of *n* agents and *m* goods. There are *m* posts, one for each good where each agent *i* bids quantity of money b_m^i and offers a quantity of goods q_m^i for sale. Let t^i be the exchange rate of i's IOUs with respect to the numeraire. The equations defining prices in terms of the unit of account are

$$p_m \sum_i q_m^i = \sum_i t^i b_m^i \qquad (1)$$

and the budget balance gives

$$t^i \sum_m b_m^i = \sum_m q_m^i p_m \qquad (2)$$

Thus each agent *i* obtains from the trading post *m* the quantities $q_m^i p_m$ units of account and $t^i b_m^i / p_m$ units of good *m*.

The system is homogeneous of order zero. If a set of prices p and a profile of exchange rates t define an equilibrium, so will λp and λt for any $\lambda>0$.

The paper of Sahi and Yao (1989) and that of Sorin (1996) establish the existence of an active[5] non-cooperative equilibrium set of prices and exchange rates and then go on to show that as the number of agents trading increases this converges to a competitive equilibrium.[6]

The credit issue of some arbitrarily selected agent can be used as a numeraire. The clearing house balances all expenditures and revenues for each agent.

2.1. The non-cooperative equilibrium solution

In Appendix C the solution is given for the non-cooperative equilibrium of the formal sell-all model that serves as the basis for the experiments reported on here.[7] For the experiment here we assume there are two types of traders, each with n agents, and there are two goods. Traders of Type 1 each own an endowment of $(a, 0)$ and traders of Type 2 each own $(0, a)$.[8] Each trader puts up all of his/her assets for sale and is allowed to "print" and bid units of a personal currency to buy each of the two goods. The reasons for having each trader sell all endowed assets are two-fold. First, this market structure cuts the size of the strategic actions of each individual to two. Also, it reflects a modern economy in which individuals buy virtually all their needs from markets, instead of consuming any significant amount of what they produce.

A strategy by an individual i is a pair of bids (b^i_1, b^i_2), $b^i_1 + b^i_2 \leq m^i$, where m^i is the amount of personal IOU s each individual has created. Formally an upper bound is needed to construct a playable game that does not lose definition by degenerating into a contest of who can name a bigger number. In practice if no bound is set the pathology does not occur. In economic reality an upper bound on the creation of an individual credit line can be introduced through a cost to the production of the credit. This could be a set up cost or a cost in proportion to the size of the credit line issued or both. With the invention of coinage a seignorage charge was introduced both to defray the expenses in production and policing and as a tax. As a first approximation one could argue that if an individual issues 10 or 100 or 1,000 units of personal IOUs or credit line the cost should be the same. This suggests that a single set up cost should be charged for the ability to issue one's own credit line. The cost could be in paying out some amount of real commodity (such as the individual's time). But once the permit to issue has been paid for, this does not bound the issue. There is nothing to stop the individual from writing a credit line for as large a number as he wishes. At this level of abstraction if one wished to be

[5] There could be an inactive equilibrium without trade.

[6] The non-cooperative equilibria need not be unique, but in this experiment the conditions were chosen so that the equilibrium is unique.

[7] We use sell-all rather than buy-sell described above for simplicity in decision making. Since all endowment of goods are automatically offered for sale, each subject has only a two dimensional decision to make, the amount of personal credit to print and how to split it into the bids in each market.

[8] In the experiment, we chose a = 200, except in two settings conducted as robustness checks (T1a_10_nze and T1a_4_nze) where we used endowments of 196/4 and 4/196 of goods A and B respectively in order to start with non-zero initial payoffs.

tidy it is easy to place an upper bound exogenously on the issue size and leave out issue costs.

Even with an upper bound U on issue, the price level can be anywhere from (0, 2U/a]. In order to determine a unique price level more conditions must be added. Our experimental results confirm that the price level can be different in each game, as that is what we observe.

With no more than ten traders in each experimental run, the influence of each trader is large enough so that the non-cooperative equilibrium can be distinguished from the competitive equilibrium. In payoffs, as shown in Table 1, the difference between the competitive equilibrium and the noncooperative equilibrium with 10 (5+5) players is about 0.5 percent. The asymmetry in holdings is much larger (about 10 percent). Furthermore, in our closed economy the difference between the non-cooperative and the competitive equilibria is manifested in income as well as expenditures. Although the payoff function is identical across traders, and is symmetric in the two goods, endowments are asymmetric—(*a, 0*) and (*0, a*). With few traders, purchases from the market for the endowed good influence the owner's income and bring more revenue from its sale back to the trader (as compared to purchase of the other good). Each individual has a per-period payoff of the form: $\alpha\sqrt{AB}$ where α is a parameter and A and B are the amounts purchased of the first and second good (recall that all goods endowments are sold).

For purposes of comparison first consider a market that uses a commodity money[9] with a fixed marginal utility as a consumption good, say the marginal utility $= \mu = 1$, the per period payoff to the individual becomes $\alpha\sqrt{AB}$ + (M-b), where the last term is the retained money balance. As shown in Huber et al. (2010), the presence of a money with marginal worth as a consumption good is sufficient to anchor the price level.

Table 1 indicates the equilibrium bids and purchases of goods by traders of Type 1 (i.e., traders with endowment of (*a, 0*)) for the two goods as the number of traders is varied when each trader is endowed with the right to issue 6,000 units of a commodity money with constant marginal utility $\mu = 1$. In competitive equilibrium, each trader bids an identical 2,000 units of money for each of the two goods, and buys 100 units of each good at a price of 20 per unit, leaving 2,000 units of money unspent. With five traders of each type, in the non-cooperative equilibrium the amount bid for the own good is 22 percent (= (2214-1811)/1811) more than the amount bid for the other (non-owned) good.[10]

In the experiments we report here, there is no commodity money to anchor the prices. Instead the individuals are given an upper bound on the amount of personal IOUs they can issue. Any price level consistent with the given bound (of 6,000 units on each

[9] The reason for noting a commodity money is that essentially it serves as an easy way to remove the possibility of many equilibria each at a different price level. The fact that the monetary commodity has a direct consumption value, and is the numeraire, removes the freedom of choice associated with an economy using fiat money or personal credit. Although it provides an interesting price contrast and opens up questions concerning the use of a clearinghouse, it is not central to our model or the experiment, and we do not develop it further.

[10] In setting T1a_4_nze, conducted as robustness check, each market is populated by only four agents. As a consequence the amounts bid for own/other goods in the non-cooperative equilibrium are 2654/1574 and thus 69 percent higher for the own good than for the other good.

trader in most treatments) would be feasible. Table 1 provides one of the many solutions consistent with individual credit.[11]

The level of overall spending is essentially irrelevant, because exchange rates will adapt; but the individual allocation of spending to buy goods A and B determines the payoff of the agents. As explained above, there is a general equilibrium solution with an equal amount of money allocated to both goods by each individual. There is also a non-cooperative equilibrium where 10 (5 + 5) participants spend 22 percent more on the good they are endowed with than on the other good. In both scenarios the overall spending level does not matter, as the exchange rates are always set to equalize each individual's spending and income.

2.2 A Continuum of Equilibria

A continuum of prices is consistent with the equilibrium distribution of resources. The clearinghouse arrangement allows for equilibrium prices to be supported with all individuals having different exchange rates. For, example, if each trader has a credit line of 6,000; total resources are (200,200) and half bid all their 6,000 (3,000 in each market) while the other half bid 3,000 (1,500 in each market) the prices at competitive equilibrium would be $p_A = p_B = 30 = (3{,}000w_A+1{,}500w_B)/200$ with the relative prices being $w_A = 1$ and $w_B = 2$. In this equilibrium each player buys 100 units of each good. Suppose now that the second traders each bid half as much, i.e., 750 instead of 1,500 the distribution of goods would still be the same and the prices at competitive equilibrium would be $p_A = p_B = 30 = (3{,}000w_A+750w_B)/200$ with $w_A = 1$ and $w_B = 4$. If both traders cut their bids in half then because player 1's currency is the numeraire and by definition equal to one, prices would be $p_A = p_B = 15$.

2.3 Numeraire

When there is a money with a constant marginal utility μ_i to each individual i, the selection of a numeraire is more or less natural; society may fix its price level at one by transforming each utility function of form $u(A_i,B_i)+\mu_i\,(m-b_i)$ to be $(1/\mu_i)u(A_i,B_i) + (m-b_i)$. When there is a government fiat money an expectation concerning its purchasing power in the next period must be given for a price to be attached to it.

When there is neither a commodity nor fiat money, the normalization can be made to anchor prices by arbitrarily choosing one of the agents and assigning weight w = 1 to him. All other weights are then calculated relative to this agent's weight. This is the method utilized in the first set of experiments. Another way of normalizing is to have all of the relative weights assigned to all of the agents add up to some constant.

[11] For the sake of comparability, we present the same solution as in Huber et al. (2008 and 2010).

3. The Experiment

3.1 Setup

In operationalizing the game as a laboratory experiment, we utilize individuals to play the role of each agent,[12] and use an instantaneous clearinghouse mechanism. Each agent can issue his or her own credit and knows that prices will emerge in such a way that all accounts will balance and that the cost of their purchases will match the revenue from their sales with no opportunity for default and no threat to their reputations.

In separate experiments with (i) human and (ii) minimally intelligent artificial agents (Gode-Sunder 1993) we chose a simple setup with ten traders, two goods (*A* and *B*), and equal (in T1a, T1a_10_nze, T1a_4_nze, T2a, T2b, and T2c) or differing (in T1b) upper limits on the personal money each trader could issue. We used the sell-all market structure in all treatments. However, while in Treatments 1a and 1b traders did not directly control the goods they were endowed with, and all units were always sold, in Treatments 2a, 2b, and 2c participants could decide how many of the promised 200 units to deliver, with any quantity from zero to 200 possible.

In all treatments traders received as income the proceeds from selling their endowments of goods at the market clearing price (this was also the case in Treatment 2 irrespective of whether they really delivered them). This can be thought of as payment in advance.

In all treatments five traders were endowed with 200 units of *A* and zero of *B*, while the other five were endowed with zero units of *A* and 200 of *B*.[13] In treatments T1a, T1a_10_nze, T1a_4_nze, T2a, T2b, and T2c each trader was allowed to issue up to 6,000 units of personal IOUs each period; in treatment T1b the allowances to print money varied – two traders (one each endowed with *A* or *B*) were allowed to print 500; 1000; 2000; 4000; and 8000 units respectively.

The key distinction between Treatments 1 and 2 is that the latter permitted subjects to fail to deliver some or all of the goods promised for delivery. In Treatment 2, as in Treatment 1, all 200 units of each participant are up for sale and prices and exchange rates are calculated the same way as in Treatment 1. Each individual earns 200 times the unit price of his endowed good as income. Given the clearance mechanism this exactly offsets his expenditures. However, in a second step introduced in Treatment 2 each participant can decide how many, if any, of his 200 endowed units to actually deliver – with zero (complete failure to deliver) to 200 units possible. When deliveries fall short of the promised quantities, unit prices and money earnings are not changed, but the units actually received are reduced proportionately for all. For example, if 10 percent of the promised units are not delivered, each trader receives 10 percent fewer units of this good without getting his money for the undelivered units refunded to him.

Treatments T2a, T2b, and T2c differed with respect to the penalty imposed for reneging on delivery of units. In T2a, the penalty was high—5 points per undelivered unit—which made it uneconomical to renege in virtually all cases. In T2b, the penalty

[12] In one market conducted as robustness check teams of two people play one agent each.

[13] This was relaxed in T1a_10_nze and T1a_4_nze where the endowments were 196/4 or 4/196 of goods A and B, respectively. With these non-zero endowments initial payoff was 280 instead of being zero. Still all goods were sold through the market. These markets are presented in section 4.2 on robustness checks.

was 2.5 per undelivered unit which made it uneconomical for some situations, but not for others to renege. In T2c, the penalty was zero, making it individually advantageous for everyone to renege. The size of this penalty can be thought of as a parameter of the strength and efficiency of the contract enforcement system. We expect that the high penalty in T2a should induce a higher level of market discipline and efficiency, while the zero penalty in T2c should result in a high level of reneging and therefore an inefficient market. In T2b we should expect an intermediate level of reneging and efficiency.

In each period of each treatment each participant decides how much money to "print" to buy goods *A* and *B*. The computer, playing the role of a clearinghouse market mechanism, constructs a matrix of all the bid amounts and inverts it to calculate prices and exchange rates so that (1) the number of units of each good bought and sold in the respective markets are equal, and (2) the net cash position of each trader is zero – this holds true also in Treatments 2, as each individual receives 200 times the price of his good, irrespective of how much she actually delivers.

Each period's earnings for each trader are calculated as ten times the square root of consumed units of good *A* times the consumed units of good *B* (i.e., the units held at the end of the period). In Treatment 1 the consumed units were the number of units of each good bought. In Treatment 2 the consumed units of the non-endowed goods were the number of units bought; the consumed units of the endowed goods were the number of units actually received from the market plus the number of units retained, i.e., not delivered.

Earnings are converted to U.S. dollars at the end of the experiment at a pre-announced rate. Traders learned about their personal, as well as the market average, earnings at the end of each period. All endowments were reinitialized at the start of each period (see Instructions in Appendix B).

3.2 Implementation

We report the results of laboratory runs of the personal IOUs experiment, and compare these results with the outcomes of the sell-all market presented in Huber et al. (2010) in which money balance had a constant marginal payoff. From July to November 2006 three runs for T1a (uniform limits on the amount of money individual subjects could "print") and two runs for T1b (heterogeneous limits on money) were conducted at Yale University. Four of the runs (two for T1a and two for T1b) were conducted each with ten undergraduate students of different departments at Yale University. Each student acted individually and no communication was allowed among them.[14] In July 2008 and January 2010 the runs of Treatment 1a_10_nze, Treatment 1a_4_nze, and Treatment 2 (two each for T2a, T2b, and T2c) were conducted at the University of Innsbruck, Austria,

[14] One run (T1a_team, presented in section 4.2. Robustness Checks) was conducted with 18 students who were primarily undergraduate majoring in economics with a few Masters degree students in management. 16 of the students were randomly assigned to eight pairs, while the remaining two students participated without a partner. This became necessary because two students did not show up as planned. While communication between participants was forbidden in the first four runs, the two students in each team had to reach a decision together and were allowed to talk. Communication across the teams was not permitted.

with an average payment of €21. The recruitment of participants was done with ORSEE (Greiner, 2004), and the experiment was computerized with zTree (Fischbacher, 2007).

3.3. Minimally Intelligent Agents

A simple decision mechanism is employed here for minimally intelligent (MI) traders (Gode-Sunder 1993). Performance of the economy with this simple algorithmic agents provides a useful benchmark for comparison against theoretical equilibria as well as experimental outcomes from laboratory in which the actual strategies of individual subjects are not only complex but also unobservable. Each agent selects randomly from its opportunity set defined by the credit restrictions, i.e., the sum of its investments in the two goods is uniformly distributed between zero and 6,000. In a second step the sum is randomly split between the two goods using a fraction which is uniformly distributed between 0 and 1. We include the results of the MI agent simulations in the following sections.

4. Results

4.1 Results of Treatment 1

In all four runs of Treatment 1 total spending (by all traders) between the two goods is balanced with investment in the "own" good, i.e. the good they are endowed with, ranging from 49.3 to 51.3. The remaining 48.7 to 50.7 percent were invested in the other good. This overall equality was observed throughout the 10-15 periods of the five runs, with no systematic change from early to later parts of the runs (see Figure 1 for details).

[Insert Figure 1 about here]

Non-cooperative equilibrium predicts that subjects in Treatment 1 will tend to bid more money for their endowed good than for the other good (see Table 1, 2214 for endowed good vs. 1811 for the other good). Treatment 1 data are weakly consistent with the non-cooperative equilibrium in three of the four runs (see Table 2). Across the four runs participants invested 51.2 percent of their money in their own good and 48.8 percent in the other good. While this imbalance points into the direction of the non-cooperative equilibrium, the spending on the own good is only 5 percent higher than the spending on the other good. The traders are therefore closer to the general equilibrium which predicts no difference in spending on the two goods, than to the non-cooperative equilibrium with a prediction of 22 percent difference. Here only run 1 of Treatment 1a is close to the non-cooperative equilibrium, while the other three runs of Treatment 1are in general equilibrium. This appears to indicate that the competitive equilibrium requires less sophistication in strategic thought than the non-cooperative equilibrium.

Over the 10-15 periods of the four runs, there is no trend in the difference between spending on the two goods—there is no indication of either narrowing or widening over time – see Figure 2, where average "symmetry" of investment is shown per period. This number is calculated by taking the amounts spent for the two goods and dividing the smaller number by the larger. If investment in the two goods is equal "symmetry" is 1; otherwise it is lower, reaching zero when only units of one good were bought. This result differs somewhat from the sell-all markets examined in Huber et al. (2010) where spending for the own good was on average 34 percent higher than spending for the other good. We think the difference might stem from the fact that subjects focused on different tasks in the two settings: in the pure sell-all markets presented in Huber et al. (2010) they had to decide how much of the money given to them should be spent on *A* and on *B*, and how much should be kept unspent. In Treatment 1 of the present experiment, by contrast, they first decide on how much money to print, possibly leaving the distribution of spending on *A* and *B* as a secondary consideration. Indeed, equal spending for the two goods is the most frequent choice made (44.2 percent of all cases).

[Insert Figure 2 about here]

In Treatments T1a and T1b spending limits seem to play only a minor role in the lab economies when it comes to earnings. This is because the relative value of IOUs issued was adjusted, thus printing and spending 1 unit of personal IOUs for each good is equal to printing and spending 3,000 units of personal IOUs for each good. The heterogeneous spending limits we set in T1b also seem to have been without much consequence: on average between 33 and 78 percent of the maximum allowed amounts were printed, with no systematic pattern visible (see Figure 3). E.g. the 33 percent were printed by subjects with the second highest spending limit in run 2 of T1b and the 78 percent were printed by those with the highest spending limit in run 1 of T1b.

[Insert Figure 3 about here]

Again we calculated 'symmetry' for each trader for each period, and period-wise averages are charted in Figure 2 with different lines for each of the five runs. Observed 'symmetry' ranges from 0.70 to 0.95 and all four runs exhibit a slight but not significant upward trend. Compared to the Huber at al. (2010) experiment, the current experiment yields significantly higher average symmetry (average of 0.83 versus 0.65 in Huber at al. (2010) all sell-all markets, Mann Whitney U-Test, $p<0.01$).

We measure allocative efficiency of the markets by the total number of points earned by traders relative to the maximum they could have earned (which is in general equilibrium). Efficiency of individual markets ranges from 96.9 to 99.3 percent; mainly because most traders invested almost equal amounts in goods *A* and *B*. By spending almost the same amounts for the two goods most traders ended up with around 100 units of each good A and B, earning close to 1,000 points per period. Learning effects are limited – mostly because participants made good choices right from the start (see Figure 4).

[Insert Figure 4 about here]

Another consequence of the equal split of investment between goods *A* and *B* by most traders is that the dispersion of the earnings of individual traders remains small; most participants in all runs earned almost the same number of total points with no major outliers.

Simulations with ten MI traders yield average earnings of 791 points, average spending of 3,000, and 'symmetry' of only 0.39. This shows that the market constraints alone help achieve a relatively high degree of efficiency even with randomly chosen bids. Compared to autarkic earnings of 0, MI traders realize almost four fifths of the CE maximum of 1,000. The human traders performed much better though, with average earnings around 990. The reason for this difference is that humans chose almost symmetric investments (symmetry of 0.83 versus 0.39 for MI agents) which generate higher earnings under the payoff function used.

4.2 Robustness Checks

To gain a better understanding of our results and to test the robustness of the setting to treatment changes we conduct three robustness checks. All three are variations of T1a. In the first robustness check we replace individual agents by two-person teams and find that the results do not change relative to the individual players. In the other two robustness checks the initial endowment is changed from (200/0, 0/200) to (196/4, 4/196), changing the autarkic utility/earnings from zero to 280 points, which is 28 percent of the maximum possible in competitive equilibrium. In T1a_10_nze (10 for 10 = 5+5 agents and "nze" for "non-zero endowments") the change of endowments is the only change as compared to T1a.

In the third robustness check, T1a_4_nze, is identical to T1a_10_nze, except that the number of agents is reduced to four (2+2). In theory (as shown in Table 1) the oligopolistic effect should be larger. The evidence supports this prediction. Results for all three robustness checks are shown in the same set of figures.

4.2.1 Robustness Check I: Teams, T1a_team

Over the past few years the question of whether and how teams behave and decide differently than individuals has become a widely discussed issue in economics.[15] We therefore ran one market where teams of two people play the role of each agent.[16] As seen in Table 2 and Figures 5-7, we do not find any marked differences from the other T1a-markets. Efficiency, own-good bias, and symmetry with the team treatment are all comparable to the runs of T1a with individuals.

[Insert Figure 5 about here]

[15] See Bosman et al. (2006), Feri et al. (2010), Kocher/Sutter (2005), and Sutter (2009a, 2009b) for seminal contributions to this discussion.

[16] Actually eight of the ten agents are two-person teams, while the remaining two agents are played by individuals. This was necessary, as two subjects did not show up for the session.

[Insert Figure 6 about here]

[Insert Figure 7 about here]

4.2.2 Robustness Check II: non-zero endowments, T1a_10_nze

In T1a_10_nze the initial endowment of each subject is either 196/4 or 4/196. Given our earnings function, pre-trading (autarkic) utility increases from zero to 28 percent of the maximum achievable in competitive equilibrium. All other features of the experiment and the instructions remain unchanged. We conducted four runs of this setting, each with 10 human traders. All markets ran for 15 periods.

As seen in Table 2 and in Figures 5-7 the results do not vary much from the results of T1a. The own-good bias is small again with only 3.3 percent more spent for the own good than for the other good. Overall average efficiency at 97.21 percent of the maximum is comparable to the efficiency of T1a where it was 96.9 to 99.3 percent. We therefore conclude that the stark choice of initial endowments a/0 is robust to changes to initial endowments which are bounded away from zero.

4.2.3 Robustness Check III: non-zero endowments and four agents, T1a_4_nze

The noncooperative model presented above predicts that the number of players on each side of the market should play a major role for the outcomes of the markets. As evident in Table 1 oligopolistic effects, like a stronger own-good bias and thus lower symmetry and lower efficiency, should be more evident in markets with fewer agents. To test this conjecture we conduct T1a_4_nze where only four agents participate—two endowed with 196/4 and the other two endowed with 4/196 of goods A/B. The model predicts that the own-good bias in these markets should be 68.6 percent and symmetry 0.59. We conducted eight runs with four subjects each for T1a_4_nze. All markets ran for 15 periods.

The results are presented in Table 2 and Figures 5-7. The results of T1a_4_nze markedly differ from the runs of T1a and T1a_10_nze: the own-good bias of 46.3 percent is lower than the theoretical prediction of 68.6 but much higher than in any other run. Symmetry is lower than in all other runs, and at the average of 0.60 it is close to the theoretical prediction of 0.59. As a consequence of uneven spending on the two goods efficiency is lower in these markets – from an average of 83.3 percent in round 1 it increases over time and reaches an overall average of 92.1 percent. This is significantly lower than in the otherwise comparable ten-person setting Ta1_10_nze (Mann-Whitney U-test, N=15, p=0.000). We therefore conclude that the theoretical prediction of lower efficiency due to stronger oligopolistic effects holds when the number of agents is smaller.

4.3 Results of Treatment 2 (Moral Hazard)

In the analysis of data from Treatment 2 we focus on the number of units delivered—the main point of departure from Treatment 1 in which subjects had no choice but to deliver all 200 of their endowed units. We also examine the consequences of the delivery choice for efficiency, whether spending patterns differ across the three levels of penalties used in T2a, T2b, and T2c, and how they compare with the spending patterns in Treatment 1.

4.3.1 Goods delivered

Figure 8 presents the average number of goods delivered per participant per period. Recall that 200 is the promised and the maximum possible delivery. The high non-delivery penalty of 5 points per unit in T2a ensured that most units (187 on average) were actually delivered and this 94 percent rate of delivery remained stable over the 20 periods in a run, i.e., the delivery in early and late periods remained essentially unchanged.

[Insert Figure 8 about here]

In Treatment T2b, with an intermediate level of penalty at 2.5 points for each undelivered unit, fewer units were delivered on average (119) and this number seemed to drop steadily from about 160 in early rounds to about 90 at the end of the runs.

Finally, without any penalty for non-delivery, the market came close to a breakdown in Treatment T2c. More than 100 units were delivered only in the first period; deliveries dropped steadily until they fell below 50 and bounced between 26 and 42 in the last seven periods. The overall average of units delivered was only 52 units = 26 percent of the maximum. Theory predicts delivery of 200 when μ = 5, delivery of 0 when μ = 0 and delivery of 100 when μ =2.5. Agents in the MI simulation randomly chose a number from zero to 200 and delivered this number. Thus, the average number of units delivered (and withheld) is 100 of the 200 initial endowment. This selection is made irrespective of the penalty.

4.3.2 Efficiency

Earnings in this game depend on the number of units of the two goods held at the end of each period. Efficiency is therefore closely related to trading and the number of units delivered. When all units are delivered and everyone's bid for good A is the same as for good B, everyone will buy and consume 100 units of each good and earn the maximum possible 1,000 points, yielding 100 percent efficiency for the economy. At the other extreme, if nobody delivered any units, everyone would end up with the 200 units he was initially endowed with, but no units of the other good. As our earnings function is multiplicative in the units of the two goods consumed, the individual payoff and the efficiency would be zero.

Figure 9 presents the period-wise efficiency of the economy for the three treatments T2a, T2b, and T2c and MI agents (three lines for the three different penalty levels). In Treatment T2a, mirroring the units of goods delivered (see Figure 8), efficiency starts

high (close to 100 percent) and quickly settles around 90 percent (the average is 91.5 percent). The high penalty ensured delivery of most of the goods and yields high efficiency. The same is not true for in lower penalty treatments T2b and T2c; in both these treatments efficiency falls from about 87 percent in the first period to 55-59 percent in the last period. Average efficiency is 71 percent for T2b and 67 percent for T2c.
In the MI agents simulation efficiency without penalties is 79 percent, but this is reduced to 54 when the penalty is 2.5, and 29 when the penalty is 5. Note that efficiency of economies populated by MI agents is lower because the asymmetric consumption of such agents yields lower payoffs. In addition, efficiency drops with increasing penalty rate because the MI agents do not adjust their behavior and end up incurring greater penalties. In contrast, human agents are disciplined by higher penalty rates to deliver more of their promised amount and incur fewer penalties.

[Insert Figure 9 about here]

4.3.3 Own-good/other-good bias

The most striking difference between the two treatments concerns the division of money spent on the own and the other goods. Recall that for Treatment 1, non-cooperative equilibrium predicts a 22 percent own-good bias in spending because higher bids will generate higher prices and thus higher cash income from selling the own good (see row 5 of Table 1). Treatment 1 data exhibit the predicted bias of the correct sign albeit smaller magnitude, and therefore weakly support the theory (rows 1-6 of Table 2).
With the possibility of reneging on the promise to deliver the own good, subjects need not spend the money to try to buy them, and in extreme case, may gain an advantage by bidding all their money for the non-owned good. The larger amount of the other good bought, together with the undelivered units of the own good, should result in high earnings – unless more/most of the traders follow this policy and only few units are traded. Treatment 2 data support this prediction: investment in the own good is always *lower* than in the other good (see the lower part of Table 2). The data show a strong "other-good" bias that becomes stronger as the penalty for non-delivery is lowered. In T2a, spending on the other good is 8.2 percent higher than spending for the own good and 93.5 percent of promised units are delivered. In T2b and T2c, spending on the other good is higher by 38.6 and 47.3 percent respectively, and the proportion of delivered units drops to less than a half and a quarter of the promised units respectively.
In addition to the averages given in Table 2, the six panels of Figure 10 present period-wise evolution of the proportion of total money bid for own good for the six runs of Treatment 2. In the high penalty Treatment 2a the amount bid for own good is barely a shade below the GE prediction of 50 percent in both runs and for all 20 periods. In the medium penalty Treatment 2b, the amount bid for the own good is distinctly lower throughout, and the gap widens even further in the zero penalty treatment 2c. Thus, traders, aware that they will retain some or all of their own goods, invest money mostly to buy the other good. These patterns are remarkably stable or even grow over the 20 periods of each run.

[Insert Figure 10 about here]

4.3.4 Symmetry

In Treatment 1 and Treatment 2a, the amount of money bid for the two goods is split close to 50-50 yielding an average symmetry measure of 0.83 in T1a, 0.86 in T1b (see discussion in Section 3.3), and 0.84 in T2a, which we consider reasonably close to 1. With unequal bids for the two goods in Treatments 2b and 2c, the symmetry measure drops sharply to 0.61 and 0.48 respectively (see Figure 11). In the MI simulations symmetry is even lower at 0.39, as agents distribute their investment randomly.

[Insert Figure 11 about here]

Figure 12 shows the period-wise symmetry measure of money bid for the two goods for three variations of Treatment 2. Symmetry measure remained stable at 0.8 or higher in T2a (high penalty), started at 0.7 and gradually dropped to 0.5 in T2b (medium penalty), and dropped from 0.55 to 0.35 over the twenty periods of T2c (no penalty). Asymmetry in the medium and low penalty treatments increased as more traders decided to bid more of their personal IOUs for the non-owned good as they shifted to the practice of delivering less of their own good.

[Insert Figure 12 about here]

4.3.5 Money Printed

We use the term individual IOU throughout this paper, but an equivalent term could be money or personal money as it is always accepted in exchange. Similar to what we saw in Treatment 1 participants in Treatment 2 printed on average between 40 and 55 percent of the maximum allowance of 6,000. Again we see a mildly increasing trend (see Figure 13). However, as discussed earlier, the total amount printed is not important; this proportion of the money printed bid for each good is the important consideration in this economy.

[Insert Figure 13 about here]

5. Discussion and Extensions

5.1 Simplicity

Building formal mathematical models frequently requires ruthless simplification by abstracting away from the details of the environment under the assumption that the outcome is robust to variations in such details. Since even subtle variations in environment may affect the outcomes, the propriety of such abstraction is settled, ultimately, through successive empirical observation of varying environments. As a starting point of this process, we have opted for symmetry and simplicity in the lab environment to compare its outcomes with the predictions of theory. A significant deviation between the two will call for revisiting the theory.

5.2 What is a Financial Instrument?

When one tries to introduce money or credit into an economic model one has to reconcile abstraction with institutional reality. As many forms of money and the credit system are manifested in information flows the exact experimental representation is difficult. For example consider a game in which payments are made in (1) coins issued by the government; (2) paper bank notes issued by the government; (3) a credit line issued by the government and utilized by the issue of checks up to a limit; (4) personal checks issued by individuals with no bound on size; and (5) ciphers typed into a computer system that recognizes them as a means of payment. All of these different physical instruments serve as a means of payment, but at some micro level they can be distinguished. They generate different costs and call for different means and levels of surveillance. In the experiments here we use ciphers entered into a computerized system which is already set up to recognize all individuals separately.

5.3. Tatonnement or others

Walras referred to tatonnement probably because this method was used by the Paris Bourse for trading of stocks. Here a different and simultaneous clearing method is used. With two trader types and two commodities tatonnement will converge to equilibrium. With three, as the Scarf (1960) example has shown, the tatonnement will not converge. Instead of tatonnement, we rely on a simultaneous clearing mechanism.

5.4 A question of Credit

In the world around us credit is used extensively to bridge problems in timing of resource flows. In these experiments the complex, but natural features of time and credit do not appear. We could introduce them fairly easily by considering preferences and endowments such that the traders wish to alternate in levels of consumption. This, in turn calls for the construction of a loan market that is not done in this paper as it would introduce problems that can be dealt with separately.

5.5 Failure to Deliver, Reputation and Default

In considering credit issue of the variety present in the free banking era when the notes of different banks sold at various discounts reflecting their reputation, it would be desirable to have an experiment that reflected this reputation. The basic experiments here do not reflect reputation because the individuals are aggregated in such a way that they are anonymous. While we have allowed failure to deliver in Treatment 2, a more sophisticated setting should include reputation and defaults.

6. Conclusions

The theoretical analysis of strategic market games indicates that an economy can attain a competitive outcome with individually issued credit lines alone, without fiat or outside or commodity money. These models also incorporate certain strong abstractions from most details observed in actual trade: (1) no transaction costs, (2) a perfect clearinghouse that balances accounts every period, (3) no intertemporal credit, (4) no possibility of a default, denying traders the opportunity to breach trust. Laboratory experiments presented here were designed to replicate the conditions postulated in such model economies (Treatments 1), or allow failure to delivery in goods with or without penalties (Treatments 2).

In the treatments without failure to deliver the clearinghouse balances all accounts each period, and rules out the many accounting problems associated with intertemporal trade. The combination of a powerful market mechanism plus a perfect clearinghouse puts enough structure on the game to prevent non-correlated, or at best weakly correlated behavior at mass scale to go far wrong. The sizes of the simple strategy sets are sufficiently constrained that markets populated with even minimally intelligent agents do reasonably well in aggregate.[17] In three robustness checks we find that neither the replacement of individuals by two-person teams, nor the use of non-zero initial endowments changes results in any noticeable fashion. However, a reduction in the number of agents (from ten to four) leads to significantly stronger oligopolistic effects including lower efficiency.

Since the design of our first treatment corresponds almost exactly to the model (with all its abstractions from real phenomena), it yields little insight into what would happen under more general conditions when one or more of these assumptions were relaxed. Treatment 2, where failure to deliver was possible, proved very insightful. It revealed that high-enough penalties for moral hazard ensured high delivery rates and thus the efficient functioning of a market. However, lower or zero penalties led to more units withheld and consequently much lower efficiency.

Our results confirm the considerable power of the market structure in promoting efficient allocation when reputation is given as perfect. We also saw that efficiency crucially depends on high enough penalties when moral hazard is possible. The key claim that government money is not needed to achieve efficient exchange can be established experimentally as well as theoretically; but the implicit utopian assumptions concerning reputation, contract adherence and clearing efficiency stress the importance of contract enforcement, credit evaluation and clearing arrangements in the economy.

Both theory and experimentation can now verify that in an ideal financial environment personal IOUs are sufficient for trade efficiency. The experimental and observational questions remain as to how these results are influenced by more realistic considerations of reputation and credit evaluation, contract enforcement and clearing arrangements.

[17] An implicit assumption in these models has been an emphasis on the role of the markets and the clearing house in promoting the efficient allocation of goods of known value. The important role of finance and markets as devices to evaluate items of uncertain worth has not been reflected in this experiment. As the tasks become more complex involving a mixture of evaluation of the quantitative and qualitative, we suspect that the distinction in performance based on expertise may emerge.

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Table 1: Non-cooperative Equilibria in the sell-all model

Players on each side	Bid for own good	Bid for other good	Bid for own/bid other	Sum of bids	Money un-spent	Price	Units of own good bought	Units of other good bought	Allocative Efficiency
2	**2653.51**	**1573.72**	**1.6861**	**4227.23**	**1772.77**	**21.14**	**125.54**	**74.46**	**96.68**
3	2382.02	1698.17	1.4027	4080.19	1919.81	20.40	116.76	83.24	98.59
4	2273.52	1767.29	1.2864	4040.81	1959.20	20.20	112.53	87.47	99.21
5*	**2213.79**	**1810.88**	**1.2225**	**4024.67**	**1975.33**	**20.12**	**110.01**	**89.99**	**99.50**
6	2175.72	1840.80	1.1819	4016.52	1983.48	20.08	108.34	91.66	99.65
7	2149.25	1862.58	1.1539	4011.83	1988.17	20.06	107.15	92.85	99.74
8	2129.75	1879.13	1.1334	4008.88	1991.12	20.04	106.25	93.75	99.80
9	2114.78	1892.14	1.1177	4006.92	1993.08	20.03	105.56	94.44	99.85
10	2102.92	1902.62	1.1053	4005.54	1994.46	20.03	105.00	95.00	99.87
many	2000.00	2000.00	1.0000	4000.00	2000.00	20.00	100.00	100.00	100.00

*Number of subject pairs in the laboratory experiment. In robustness check III (T1a_4_nze) the number of players on each side is 2; in all other sessions it is 5.
Money endowment = 6,000 units per trader
Goods endowment = (200,0) for one member and (0,200) for the other member of each pair of traders in all sessions except in robustness checks II and III (T1a_10_nze and T1a_4_nze) where the endowments are (196,4) and (4,196), respectively.

Table 2: Percentage of total spending invested in the own good and the other good in all treatments

Treatment 1	Spending for the own good	Spending for the other good	Own-good-bias*	Own-good-bias (as %age of other good)**
T1a, run 1	54.3%	45.7%	8.6%	18.8%
T1a, run 2	50.0%	50.0%	0.0%	0.0%
T1b, run 1	52.3%	47.7%	4.6%	9.6%
T1b, run 2	51.0%	49.1%	1.9%	3.9%
Avg. T1a	**52.2%**	**47.9%**	**4.3%**	**9.4%**
Avg. T1b	**51.6%**	**48.4%**	**3.3%**	**6.8%**
T1a_team	50.7%	49.4%	1.3%	2.6%
T1a_10_NZE	50.8%	49.2%	1.6%	3.3%
T1a_4_NZE	59.4%	40.6%	18.8%	46.3%
Treatment 2				
T2a, run 1	49.4%	50.7%	-1.3%	-2.6%
T2a, run 2	46.4%	53.6%	-7.2%	-13.4%
T2b, run 1	42.3%	57.8%	-15.5%	-26.8%
T2b, run 2	33.9%	66.2%	-32.3%	-48.8%
T2c, run 1	34.2%	65.9%	-31.7%	-48.1%
T2c, run 2	34.9%	65.1%	-30.2%	-46.4%
Avg. T2a	**47.9%**	**52.1%**	**-4.3%**	**-8.2%**
Avg. T2b	**38.1%**	**62.0%**	**-23.9%**	**-38.6%**
Avg. T2c	**34.5%**	**65.5%**	**-31.0%**	**-47.3%**

*Own-good-bias: the percentage spent for the own good minus the percentage spent for the other good.
**The final column presents this bias as percentage of the spending for the other good

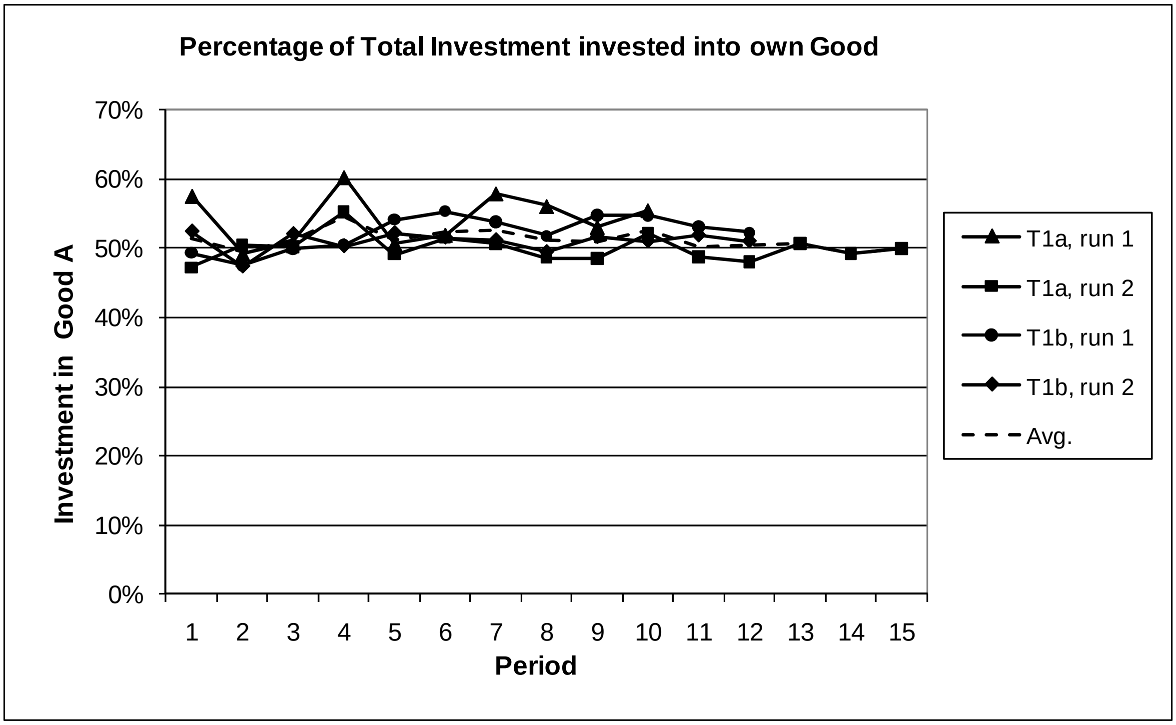


Figure 1: Investment in the own good as a percentage of total investment in treatment 1a and treatment 1b

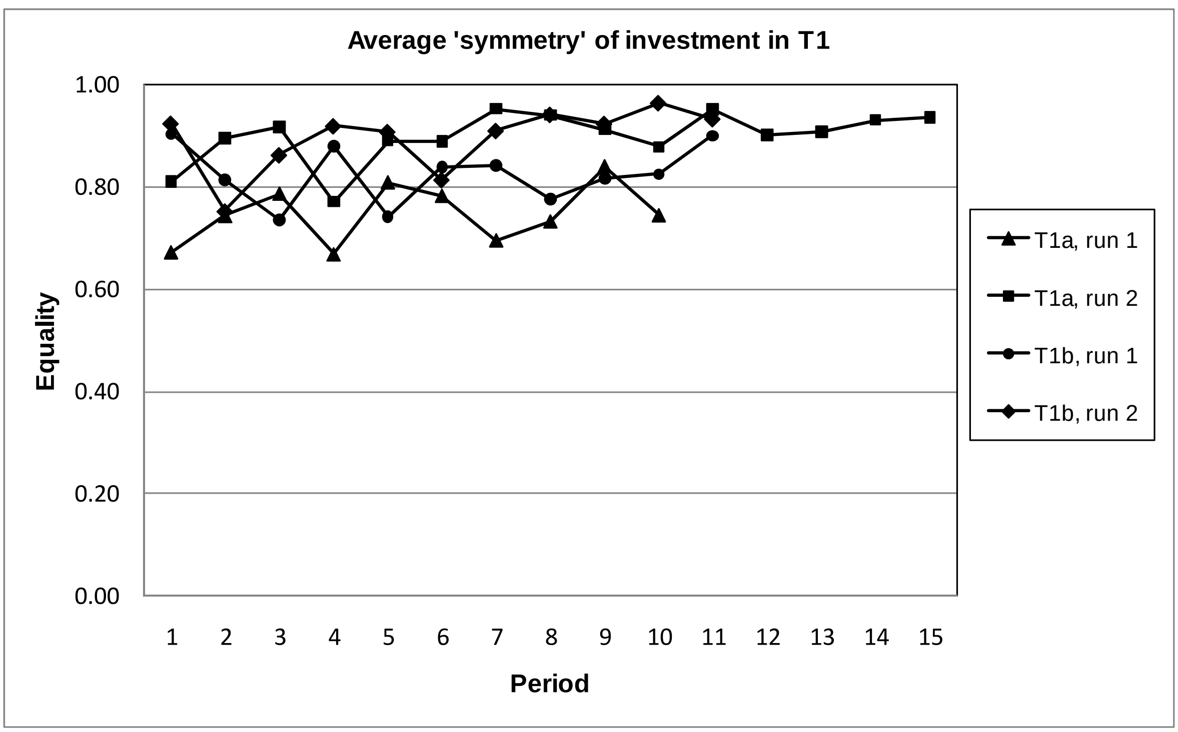


Figure 2: Average 'symmetry' of investment in the experimental runs of treatment 1a and treatment 1b

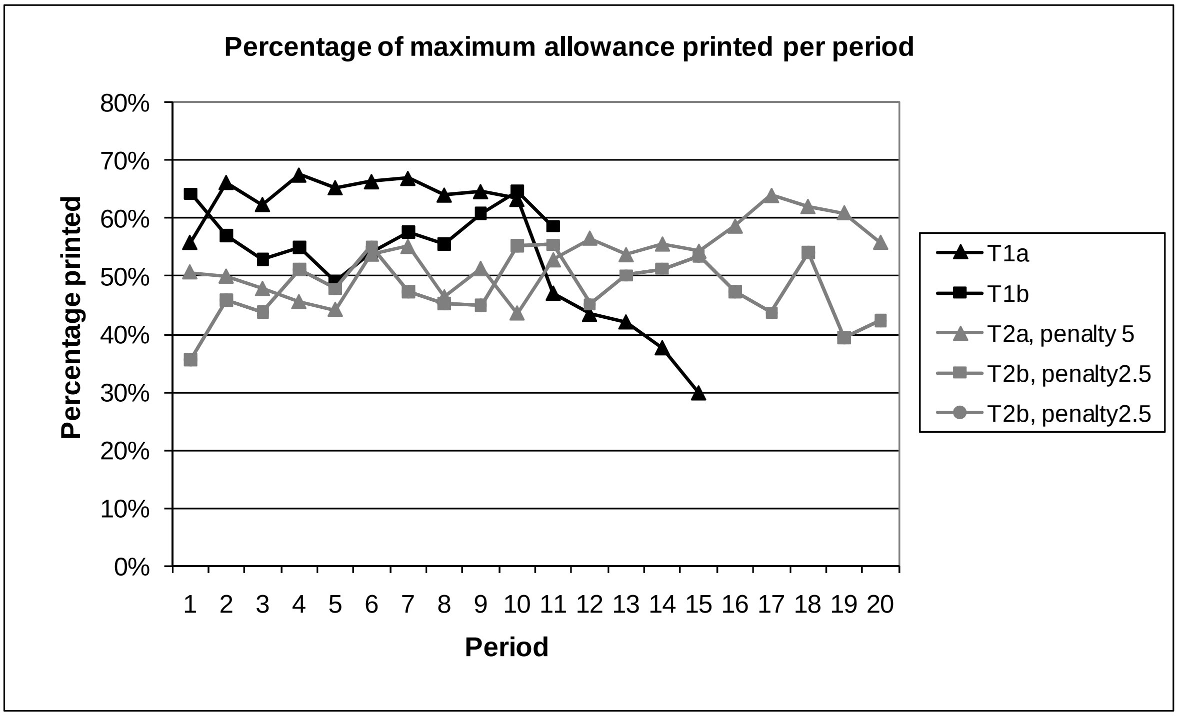


Figure 3: Average Amount of Money Printed per Period as a Percentage of Maximum Allowed in Treatments 1 and Treatments 2

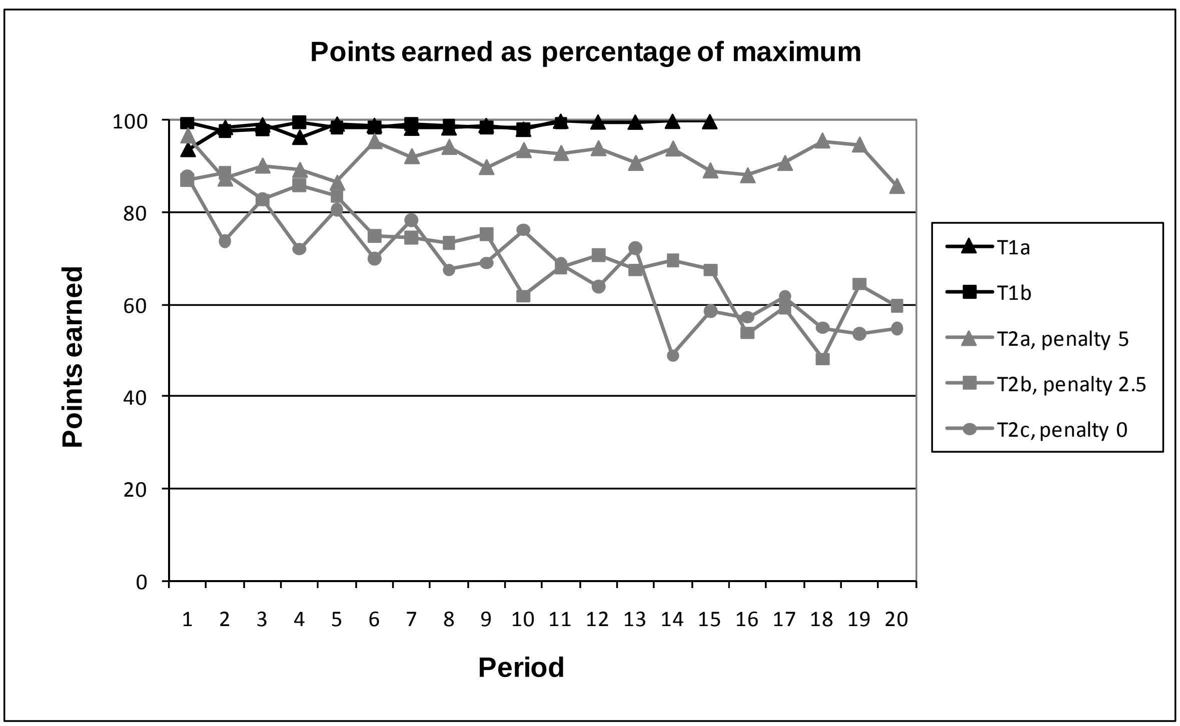


Figure 4: Average points earned as a percentage of the maximum possible in the experimental runs of treatment 1 and 2.

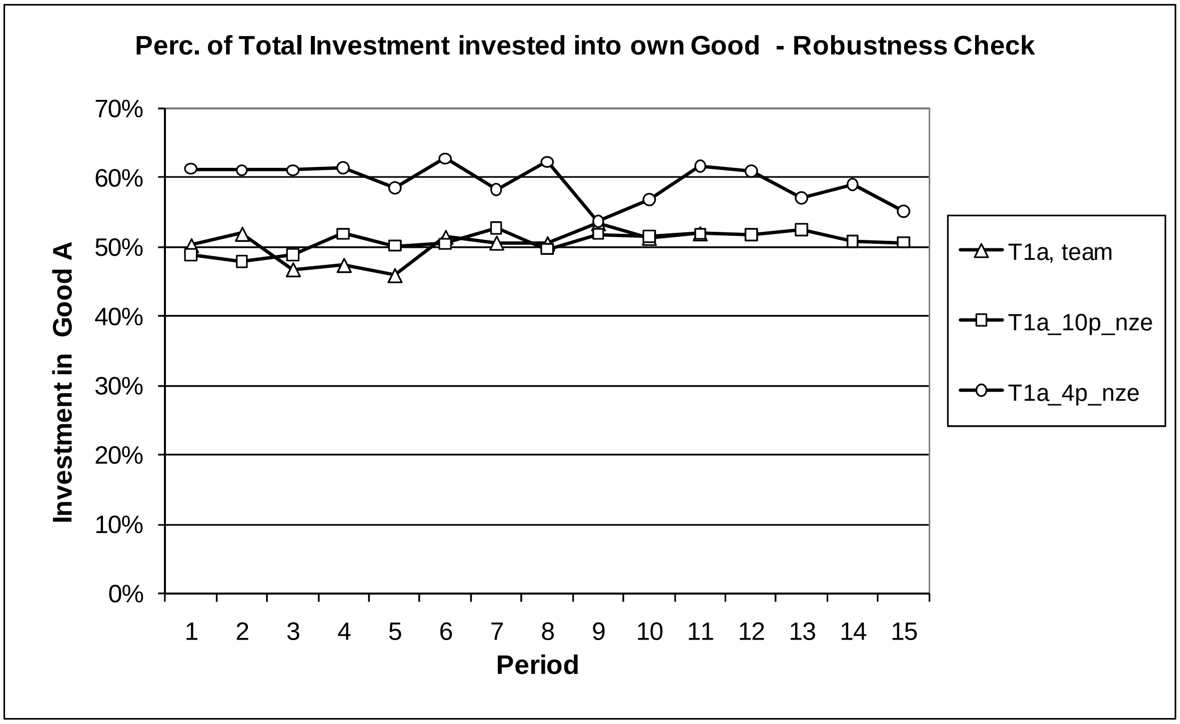


Figure 5: Investment in the own good as a percentage of total investment in robustness checks I to III (Ta1_team, T1a_10-nze and T1a_4_nze).

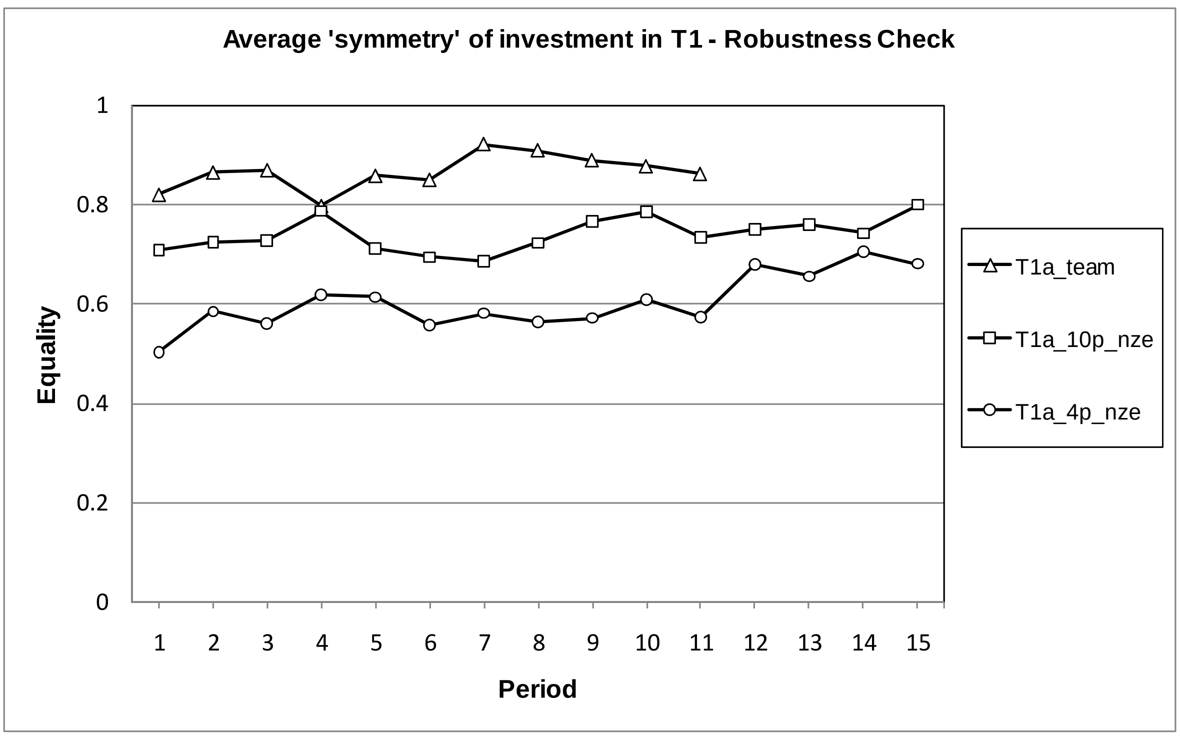


Figure 6: Average ‘symmetry’ of investment in robustness checks I to III (Ta1_team, T1a_10-nze and T1a_4_nze).

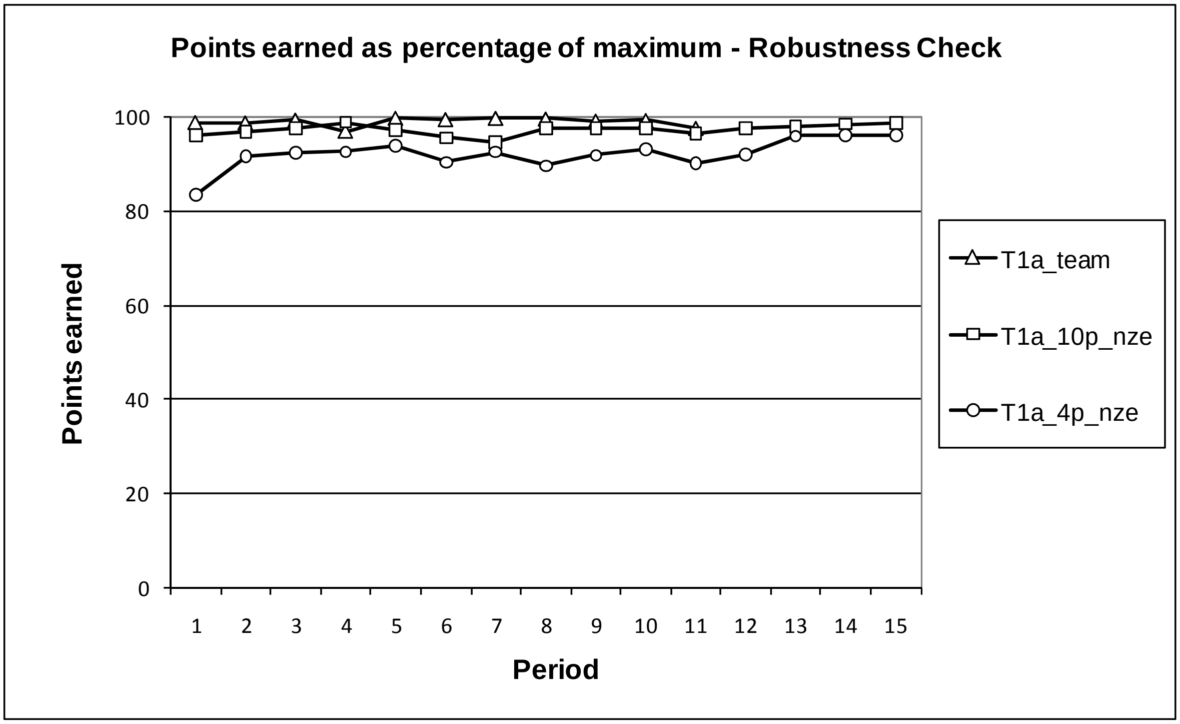


Figure 7: Average points earned as a percentage of the maximum possible in the experimental runs of treatment 1 and 2.

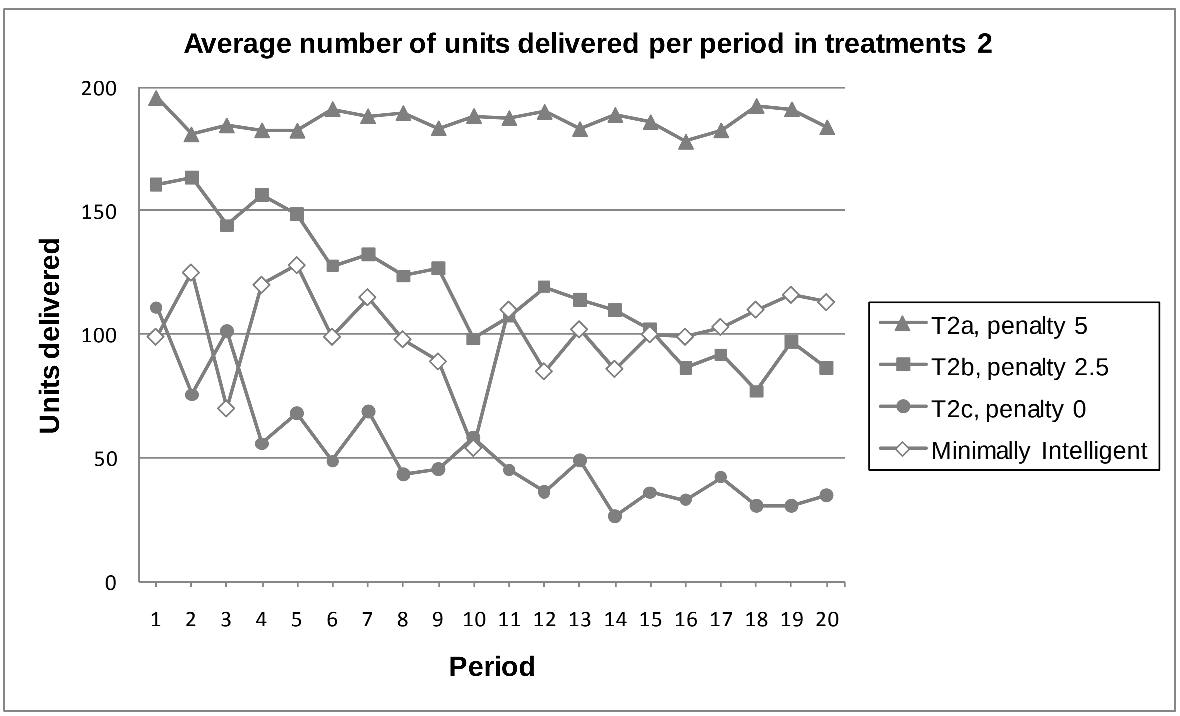


Figure 8: Average Number of Units Delivered per Period in Treatments T2a, T2b, T2c and by minimally intelligent traders

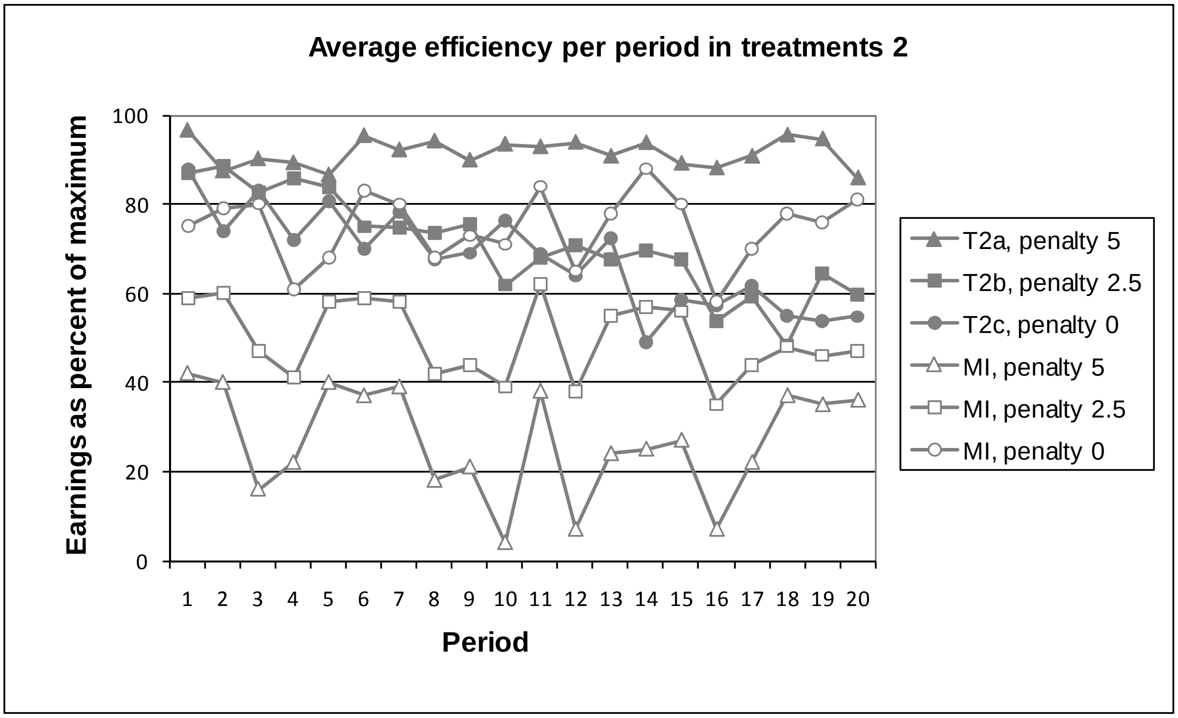


Figure 9: Average Efficiency per Period in Treatments T2a, T2b, T2c and by minimally intelligent traders

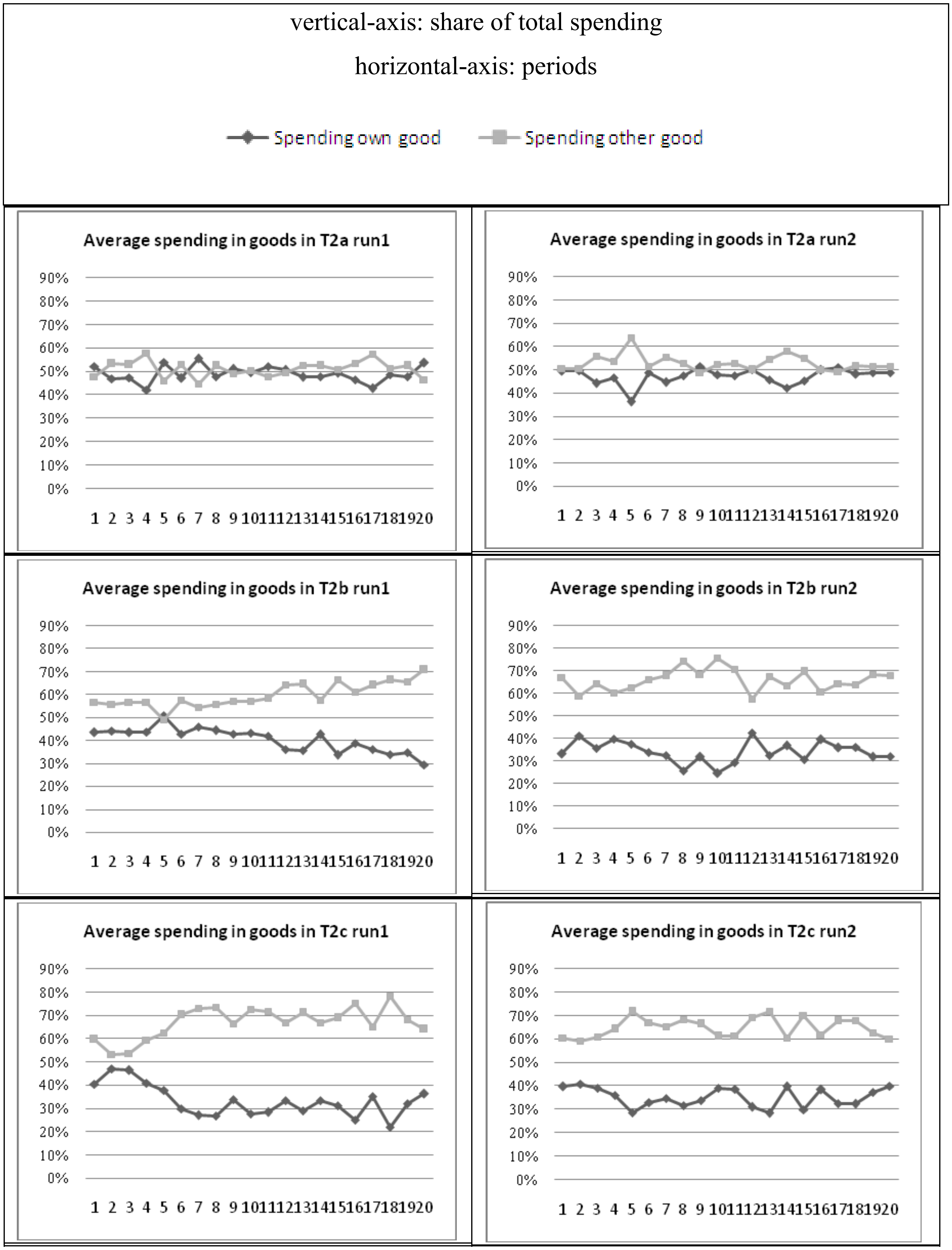


Figure 10: Period-wise Share of Money Bid for Own-Goods

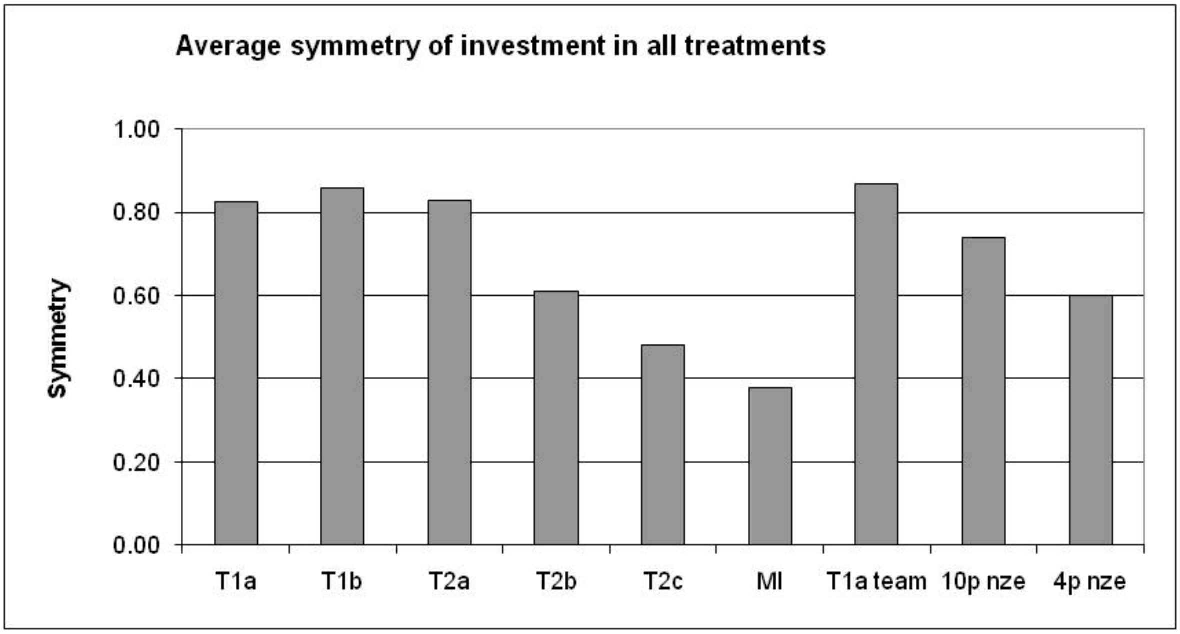


Figure 11: Average Symmetry of Money Bid for the Two Goods in Each Treatment

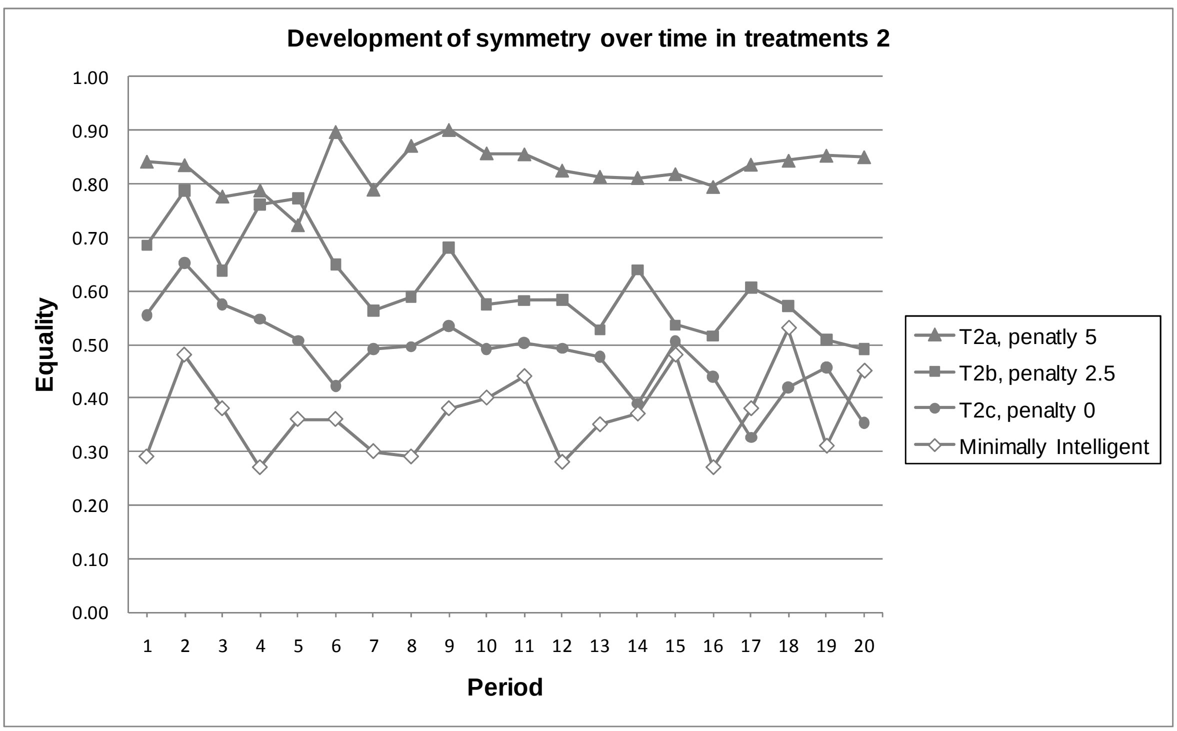


Figure 12: Period-Wise of Symmetry of Money Bid for the Two Goods over Time in Treatment 2

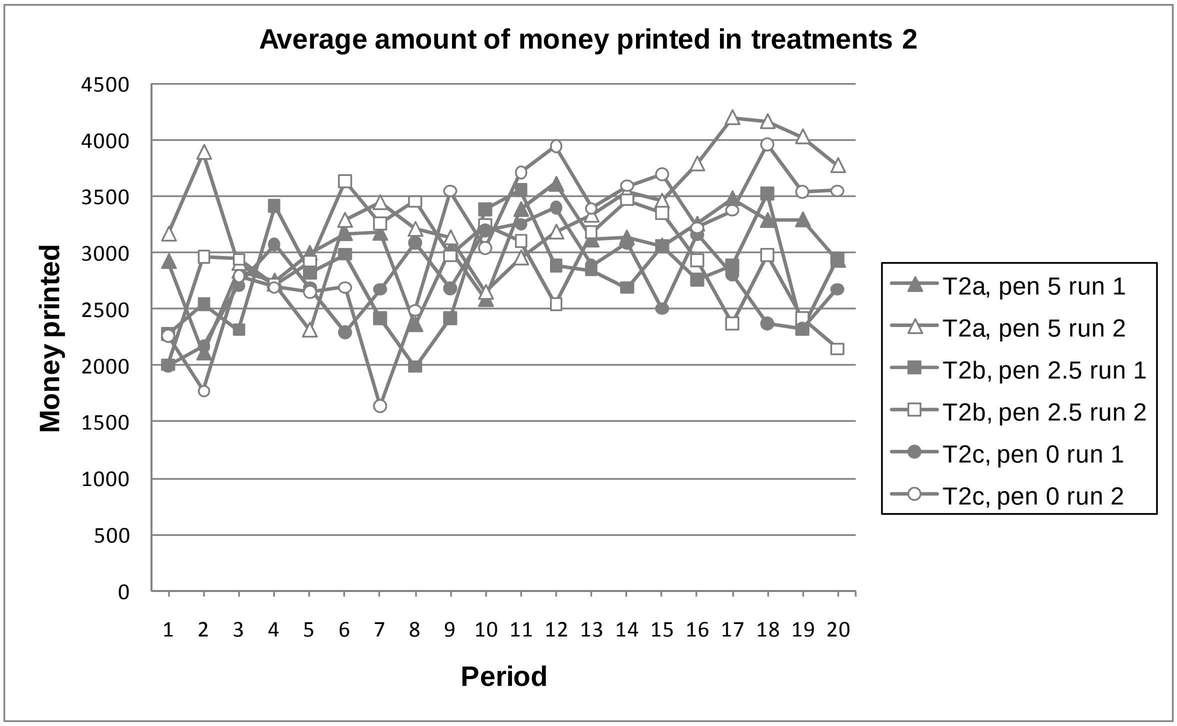


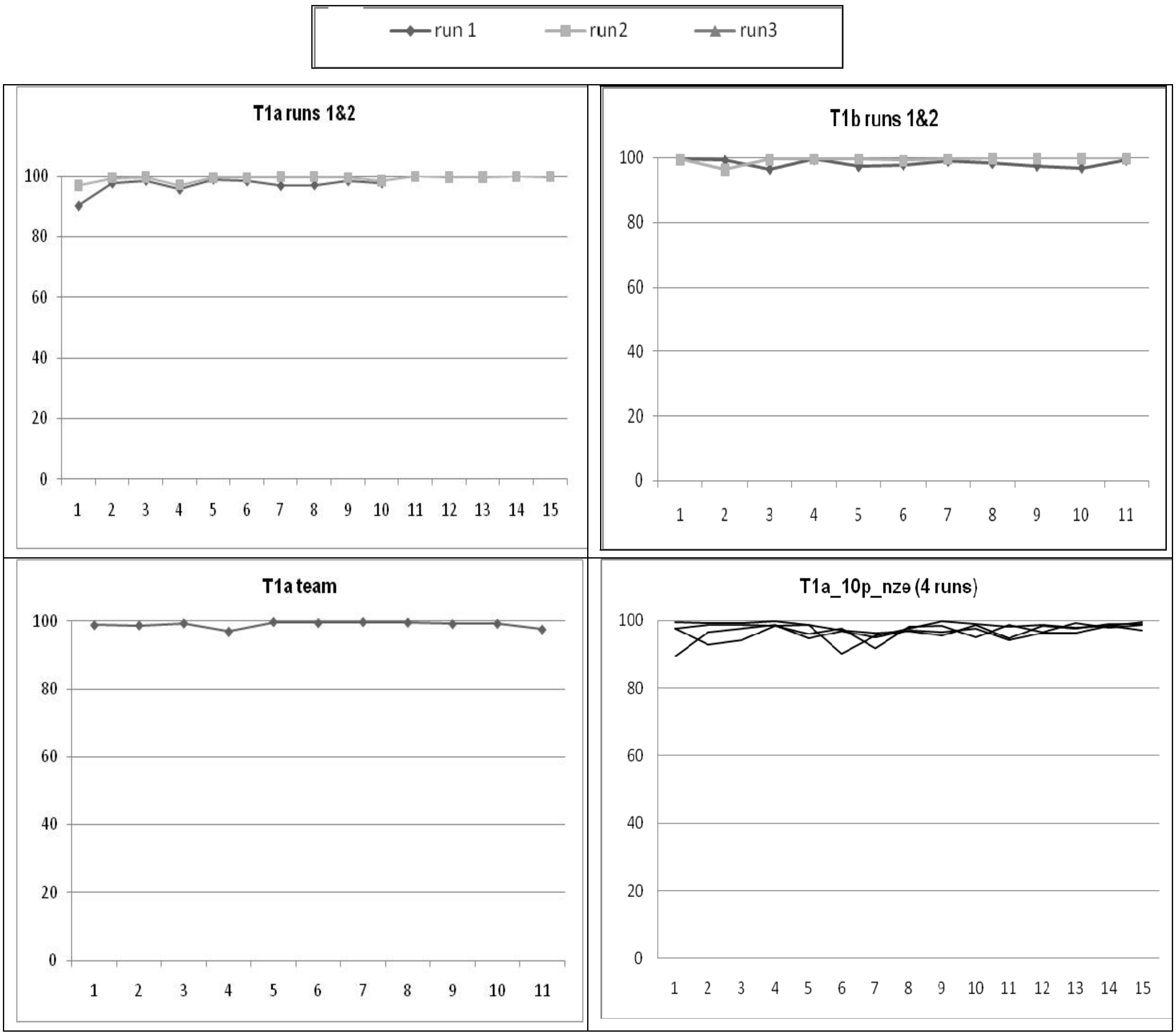
Figure 13: Average Amount of Money Printed per Period in the Runs of Treatment 2.

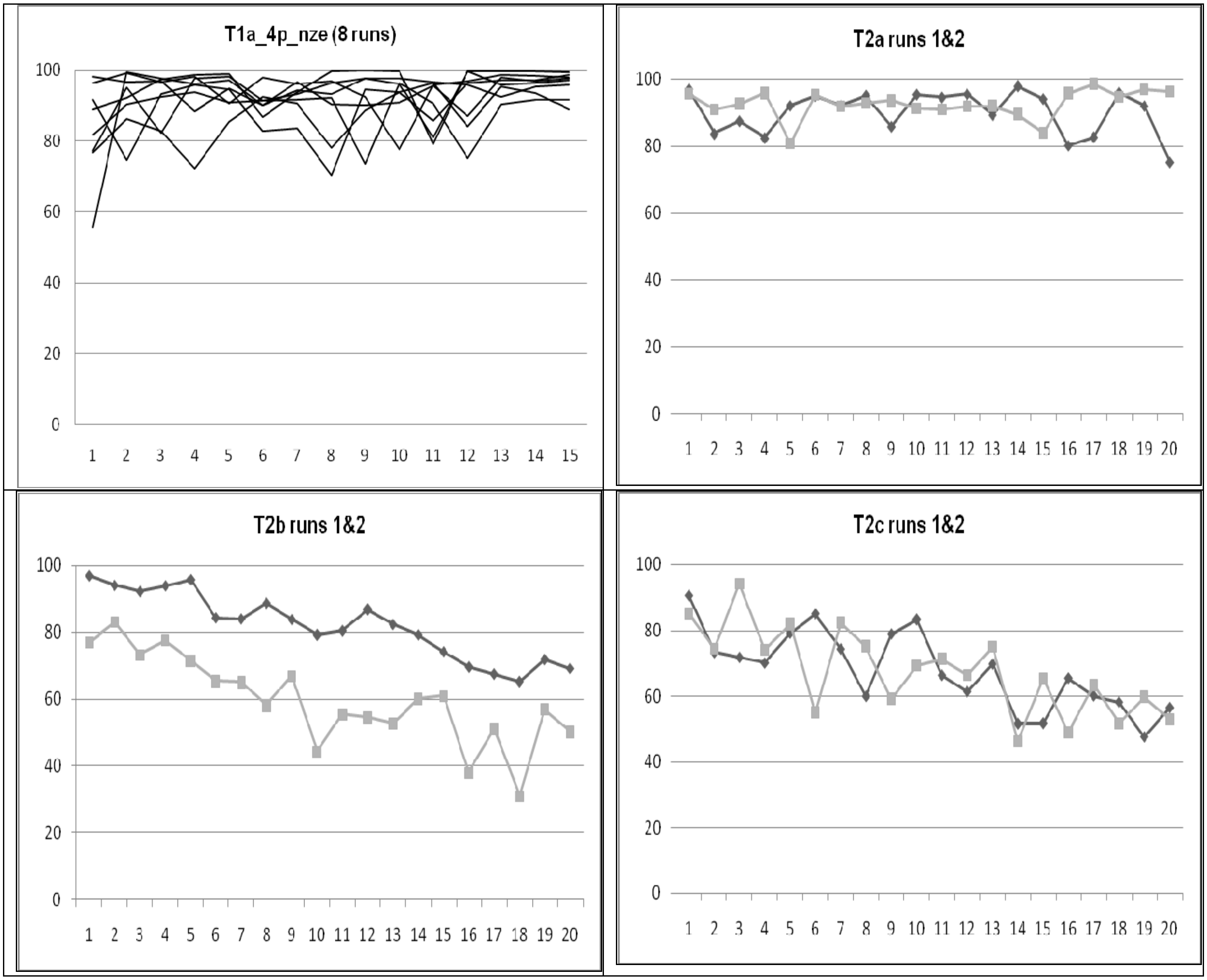
Appendix A

Average earnings per period as percentage of maximum

vertical-axis: points earned, horizontal-axis: period

Results per run for T1 and T2




T1a_4p_nze (8 runs)
0 20 40 60 80 100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
T2a runs 1&2
0 20 40 60 80 100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
T2b runs 1&2
0 20 40 60 80 100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
T2c runs 1&2
0 20 40 60 80 100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Appendix B

General

This is an experiment in market decision making. The instructions are simple, and if you follow them carefully and make good decisions, you will earn more money, which will be paid to you at the end of the session.

This session consists of several periods and has 10 participants. At the beginning of **each** period, five of the participants will receive as income the proceeds from selling 200 units of good A, for which they have ownership claim. The other five are entitled to the proceeds from selling 200 units of good B. In addition each participant will have the right to print and pay up to a maximum of 6,000 units of your own "personal" currency to buy goods A and B.

During each period we shall conduct a market in which the prices per unit of A and B will be determined. Since different participants may print different amounts of "personal" currency, the prices of goods A and B in different currencies will generally be different. All your units of A (or B) will be sold at this price (in your personal currency), and you can buy units of A and B at this price with your "personal" currency. The following paragraph describes how the price per unit of A and B will be determined.

In each period, you are asked to enter the amount of cash (units of your "personal" currency) you are willing to print and pay to buy good A, and the amount you are willing to print and pay to buy good B (**see Figure 1**) during the current period. The sum of these two amounts cannot exceed the maximum amount you are allowed to print during the period (6,000 units of currency). If the currency amounts you enter, or the sum of these two amounts exceeds the maximum permissible limit of 6,000 units, the program will give you an error message. You must reduce the amounts to proceed to the next stage. Please note that how much currency you print is your own choice.

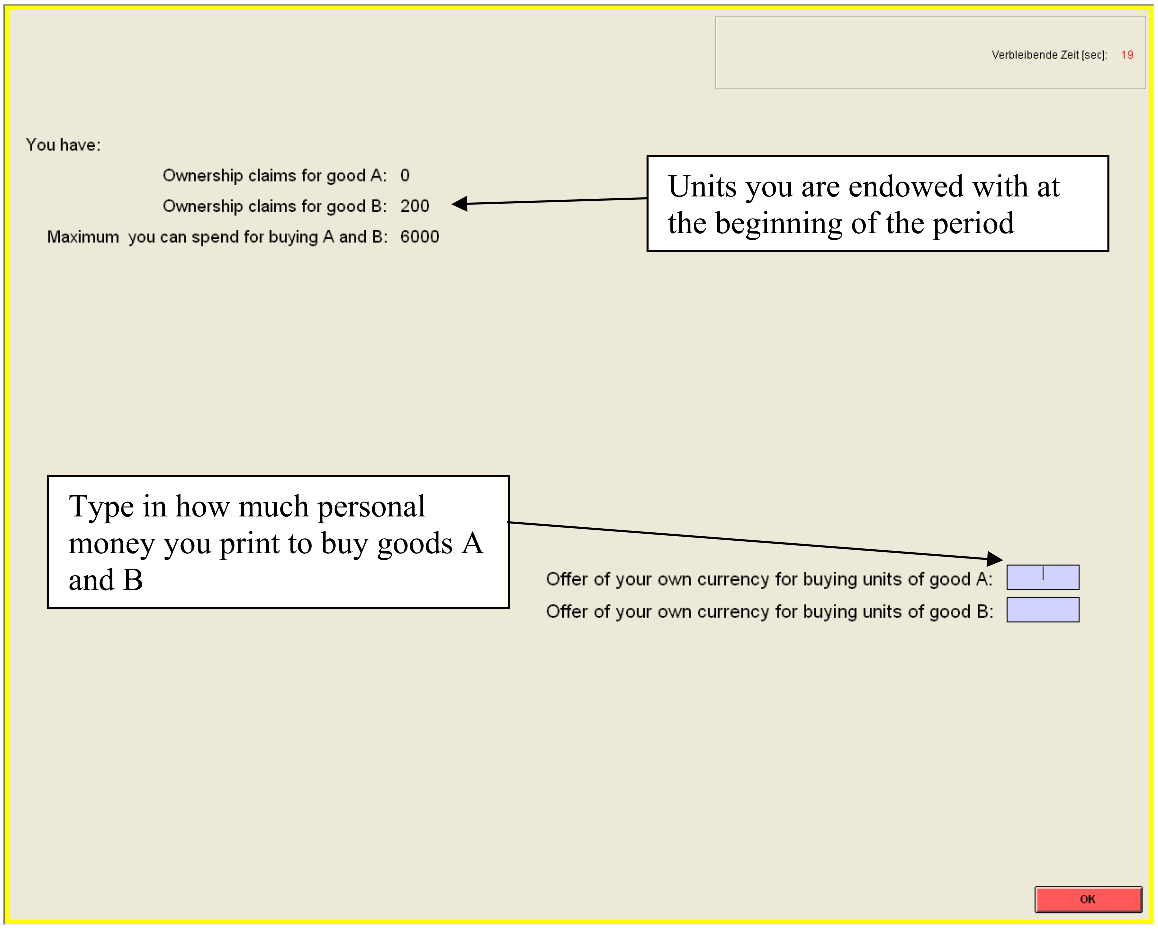


Figure 1: Screen 1, Currency offer

The computer will consider the money offered by every participant for good A. It will also calculate the total number of units of good A available for sale (1,000 as we have five participants, each with 200 units of good A). The same procedure is repeated for Good B. The computer will then calculate the prices of goods A and B, in units of the "personal" currency of each participant, so that the following conditions are satisfied:

(1) For each trader, the proceeds from sale of goods A and B equal the amount of "personal" currency printed and offered to buy goods A and B (see the net cash statement in figure 3).

(2) For each, good A and B, the total number of units offered for sale is equal to the total amount bought at the market prices.

Note that since different traders may print different amounts of their "personal" currency, the price of goods specified in units of the "personal" currency of different traders may be different. For example if Trader 1 prints more currency than Trader 2, each unit of Trader 1's currency may buy fewer goods than each unit of Trader 2's currency.

The amount of currency you earn by selling the units of Good A (or B) given to you will be equal to the amount of currency you printed and offered to buy goods A and B, and your net balance of currency will be zero (see (3) in figure 3.

If you offered to pay m_A units of your "personal" currency for good A, and m_B units of currency for good B, and the prices of goods A and B (in units of your personal currency) are p_A and p_B respectively, you get to buy (and consume) $c_A = m_A/p_A$ units of good A and $c_B = m_B/p_B$ units of good B.

The number of units of A and B you consume, will determine the amount of points you earn for the period:

Points earned = 10* squareroot of (c_A*c_B).

Example: If you buy 100 units of A and 25 units of B in the market you earn

10 squareroot (100 * 25) = 500 points.*

Non-Delivery of Promised Units and Penalty

- After the announcement of the prices and the distribution of goods, you have the option to deliver less than the full promised quantity (200) of the goods you are endowed with. If you deliver less, the following consequences follow:
- You get to keep the goods you did not deliver and therefore earn more points.
- Non-delivery means that there are fewer units of the good on the market, and therefore all buyers receive proportionately fewer units compared to what was announced.. For example, if one trader delivers only 100 units good A while the other four deliver all 200 of their units, only 900 units of this good are on the market (instead of 1000) and each trader will receive only 90% of the units he paid for.
- All payments are made in advance of delivery with no recourse. This means that (1) sellers get paid for all 200 units even if they do not deliver the full amount; and (2) buyers pay the full price for the units they were supposed to get even if they do not get all the promised units.
- Penalty of Non-Delivery. For each unit you do not deliver, 5/2.5 points are deducted at the end of this period. (See the following two examples)

Because of the amount you printed you receive 120 units of good A and 90 of good B → your earnings are therefore 10 $(120*90)^{0.5}$=1039. You decide to keep 10 units of your good and deliver 190. Therefore you have more goods and receive → 10* $((120+10)*90)^{0.5}$=1082. But for each unit you did not deliver a point deduction of 2.5 points is executed → your final earnings are therefore 1082-10*2.5=1057 points.*

You receive 70 units of good A and 110 of good B →10 $(110*70)^{0.5}$=778. You decide to deliver only 100 units of good B you are endowed with and keep the other 100 units. As a result each trader receives only 90% of the original distribution; naturally also you get only 0.9x110=99 units from the market. You keep another 100 and therefore have 199 units → 10* $(70*199)^{0.5}$=1180 points. But for each unit you did not deliver 2.5 points are deducted → your final earnings are therefore 1180-100*2.5=930 points.*

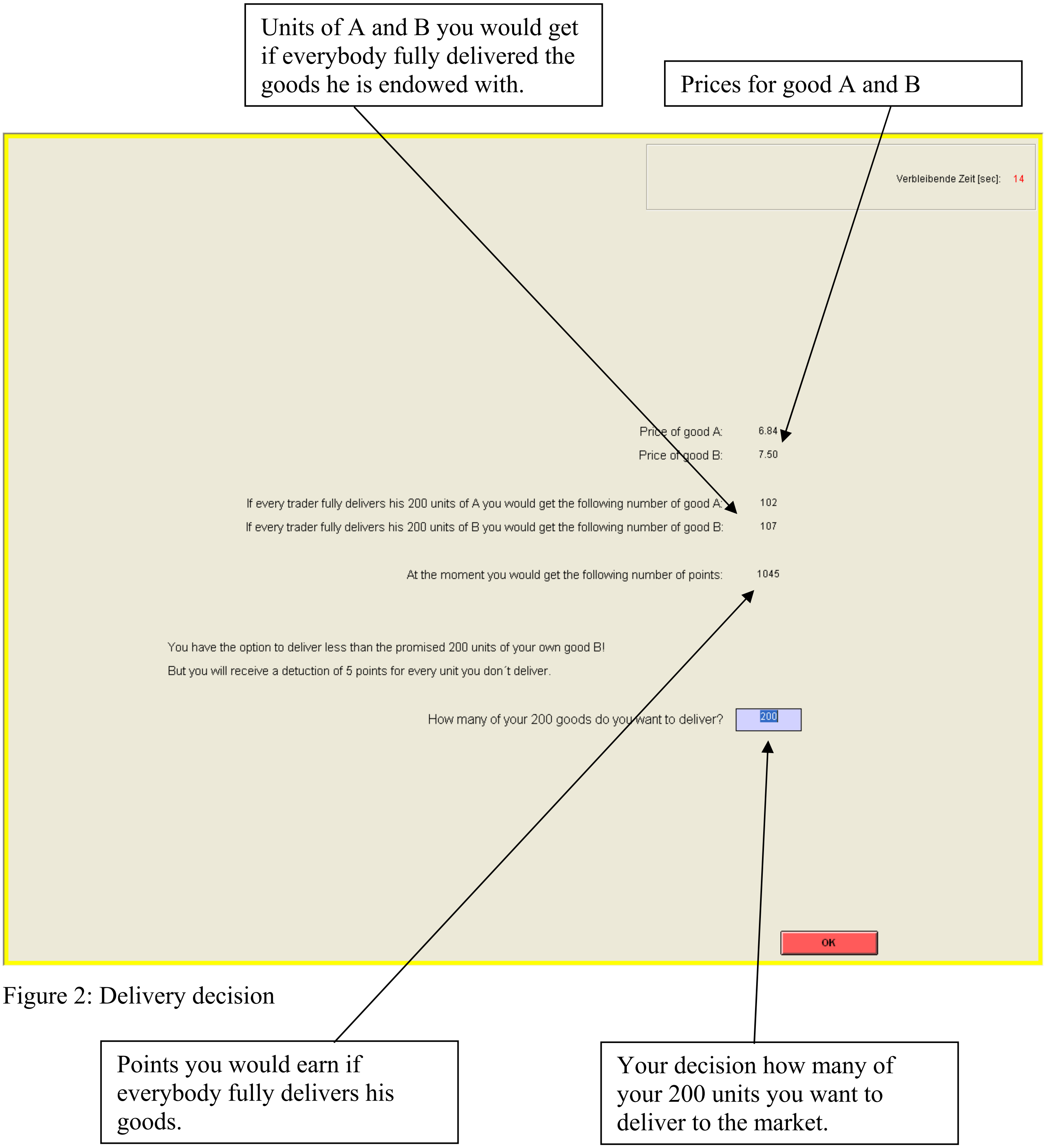


Figure 2: Delivery decision

How to calculate the points you earn:

The points earned are calculated according to the following formula:

Points earned = 10 x squareroot (c_A * c_B)

To give you an understanding for the formula the following table might be useful. It shows the resulting points from different combinations of goods A and B. It is obvious that, that more goods mean more points.

Points Earned When You Consume Varying Amounts of Goods A and B

	Units of good B you buy and consume										
Units of A you buy and consume	**0**	**25**	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
0	0	0	0	0	0	0	0	0	0	0	0
25	0	250	354	433	500	559	612	661	707	750	791
50	0	354	500	612	707	791	866	935	1000	1061	1118
75	0	433	612	750	866	968	1061	1146	1225	1299	1369
100	0	500	707	866	1000	1118	1225	1323	1414	1500	1581
125	0	559	791	968	1118	1250	1369	1479	1581	1677	1768
150	0	612	866	1061	1225	1369	1500	1620	1732	1837	1936
175	0	661	935	1146	1323	1479	1620	1750	1871	1984	2092
200	0	707	1000	1225	1414	1581	1732	1871	2000	2121	2236
225	0	750	1061	1299	1500	1677	1837	1984	2121	2250	2372
250	0	791	1118	1369	1581	1768	1936	2092	2236	2372	2500

Examples:

1) If you buy 50 units of good A and 75 units of good B, then your points earned are = 10 x squareroot (50 * 75) = 610.
2) If you buy 150 units of good A and 125 units of good B, then your points earned are = 10 x squareroot (150 * 125) = 1370.

Summary table

After each period a summary table (see figure 3) is displayed. On this table you can retrieve information about the current and past periods.

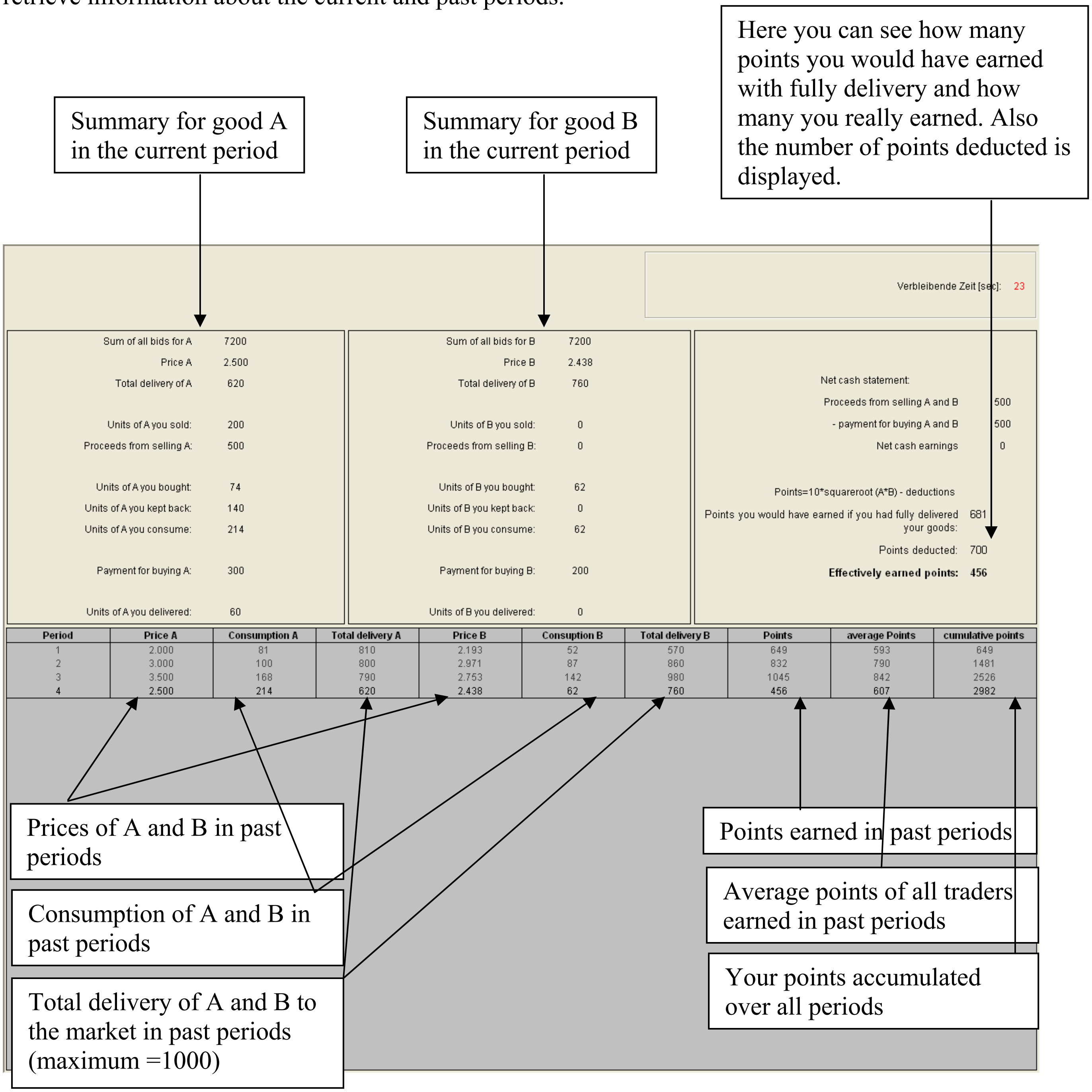


Figure 3: Summary table

Questions

General Questions.

1. What will you trade in this market?
2. How many traders are in the market?
3. How are your total points converted into euros?
4. Are you allowed to talk, use email, or surf the web during the session?

Questions on how the market works

5. What is your initial endowment of good A at the start of each period?
6. What is your initial endowment of good B at the start of each period?
7. What is the maximum number of currency units you are allowed to print in a period?
8. What is the maximum amount you can offer to buy units of good A?
9. What is the maximum amount you can offer to buy units of good B?
10. What is the maximum amount you can offer to buy A and B combined?
11. What happens to the units of A (or B) in your initial endowment?

Profits and Earnings

12. Indicate whether each of the following statement is true or false.
13. For each participant, the amount of "personal" currency received from sale of the endowment of goods (200 units of either A or B but not both) will be exactly equal to the amount of personal currency offered to buy goods A AND B.
14. The total number of units of goods A bought by all participants is exactly equal to the total number of good A endowed to all participants.
15. The total number of units of goods B bought by all participants is exactly equal to the total number of good B endowed to all participants.
16. Each unit of your "personal" currency has the same value (purchasing power) as each unit of the "personal" currency of the other participants.
17. If you offered 2,000 to buy good A and the price (in your "personal currency") is 20, how many units do you buy?
18. If you offered 2,500 to buy good B and the price (in your "personal" currency) is 10, how many units do you buy?

19. You offered 300 units of your "personal" currency to buy A and 200 units to buy B. The prices are 2.5 for A and 2.0 for B respectively.
    a. How much do you earn from selling your 200 units of A?
    b. How many units of A do you buy?
    c. How many units of B do you buy?
20. If you bought 150 units of A and 125 units of B, what are your earnings in points for this period?

<u>Failure to deliver and point deductions</u>

21. *Y*ou deliver all units you are endowed with and do not keep any. How many points are deducted from your profit?
22. You hold 20 units of your good A back. How many points will be deducted?
23. True or false? If you do not fully deliver for several periods, point will be deducted in each of the periods.
24. True or false? Whatever the point reduction will be, my profit will always be higher if I do not fully deliver.
25. You receive 111 units of good A and 50 units of good B from the market. You would consequently earn 745 points. Now you decide to deliver only 100 of your units A. Because of your decision every trader gets 10% of good A less. You also get only 100 instead of 111. How many points do you earn…
    a. … before the point deduction?
    b. … after the point deduction?
    c. Did you get a higher profit because of your decision to not fully deliver?

Appendix C

Specific Solution to Non-Cooperative Equilibrium for Sell-All

Notation

b^{ir}_j =the bid of individual i (i=1,…,n) of type r (r=1,2) in market j (j=1,2)
α = utility function scaling parameter
p_j= price of commodity j
m = initial money holding of each trader
(a,0) = initial holding of goods of type 1
(0,a) = initial holdings of goods of type 2.

The individual 2 wishes to maximize his payoff function which is of the form:

$$\Pi = A\sqrt{\frac{b_1^{i1}b_2^{i1}}{p_1p_2}} + (m - b_1^{i1} - b_2^{i2} + p_2a)$$

and similarly for Player 2.

The calculation for the sell-all model requires to solution of the two equations derived for each trader from the first order conditions on the bidding in the two goods markets. By symmetry we need only be concerned with one type of trader.

We obtain the equation

$$\frac{b_2}{b_1}\left(\frac{(n-1)b_1 + nb_2}{nb_1 + (n-1)b_2}\right) = \frac{n}{n-1}$$

and can utilize this to calculate Table 1.

The model in this paper generates the same real goods solution as the sell-all with the modificaton involving the clearinghouse weights of individual currencies. This solution applies when all of the weights equal one. Without further calculation we may adjust the solution for different exchange rates by observing that the balance equation in the new problem has the amount of money issued by an individual times its exchange rate always equal to the amount of money used by an individual in the old problem.