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THE VALUE OF FIAT MONEY WITH AN OUTSIDE BANK: AN EXPERIMENTAL GAME[#]

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Abstract

Why people accept intrinsically worthless fiat money in exchange for real goods and services has been a longstanding question. There are many competing sufficient explanations that may confound each other in practice but can be individually tested in isolation experimentally. In this paper we examine a sufficient explanation of the value of fiat money through the existence of a debt instrument which allows consumption to be moved earlier in time. We present experimental evidence that the theoretical predictions about the behavior of such economies work reasonably well in a laboratory setting. The import of this finding for the theory of money is to show that the presence of a societal bank and default laws provide sufficient structure to support the use of fiat money, although many other institutions such as taxation provide alternatives.

JEL-classification: C73, C91

Keywords: experimental gaming, bank, fiat money

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1. INTRODUCTION

In this paper, we test experimentally the proposition that the presence of an outside or central bank is sufficient to support the value of fiat money in a closed economic system with money as the medium of exchange. Prior studies have examined other sufficient conditions, or have used open models; the use of closed models to study the roles of money and financial institutions remains uncommon.[1]

Monetary economics is peculiarly institutional as it deals with dynamics, and institutions are society's way of providing carriers of process. Many different mechanisms can provide a given financial function. The introduction of an outside agency or central bank that actively or passively controls the money supply is simple. In practice, individual indebtedness to the government is achieved through taxation instead of loans. Furthermore, as in history and life in general, there are no natural initial or terminal points to the economic process. Experimentation in a laboratory requires that initial and terminal conditions be specified. This calls for care in modeling and simplification to avoid a mismatch between theory and experimentation. In particular, our introduction of an outside bank at a high level of abstraction is little more than a passivel device to provide a flexible fiat money supply by making loans at a fixed rate of interest.[2]

What the source and distribution of the initial supply of fiat money is, and where this supply goes at the end, are not usually addressed in most economic models. Implementing the economy as a finite playable game forces one to address explicitly these questions, and keep the accounting straight. The initial money holdings are held free and clear like many real assets. At the end of the finite time that the game lasts, this outside money has been consumed by interest payments to the outside bank. It is as though the government, by distributing pieces of paper to agents in appropriate proportions, initially provides them an interest free loan that can be used to finance working capital. This was the basic idea in Shubik's (1980) simple model developed further in Dubey and Geanakoplos (1992). In an infinite horizon economy the value of

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[1] Other sufficient conditions have been tested, for example, in the work of McCabe (1989), Lim et al. (1994), Marimon and Sunder (1993), and Duffy and Ochs (1999). See Friedman and Rust (1993) for double auctions in open economies; Marimon and Sunder (1993) for the role of money in closed overlapping generations model.

[2] Game theoretically the outside bank is a strategic dummy; it has neither a utility function nor free strategic choice. An experimental exploration of the role of the central bank as an active control agent requires a separate investigation.

fiat is sustained by mutually consistent expectations. In a finite economy, the device of being able to borrow, combined with competition, enables the agent to prevent the "waste" of any fiat as the loans enable them to utilize the final delayed income payments to settle their indebtedness.[3]

Hahn (1965, 1971), Jevons (1875), Shubik and Wilson (1977), Bewley (1986), and Kovenock and de Vries (2002) among others, have offered various reasons for the value of fiat or symbolic money. They are but a few studies from an extensive literature on the subject most of which provide sufficient, but not necessary conditions. These reasons are that: (1) since money is assumed to be wanted by all, it serves as a low cost means to overcome the failure of the double coincidence of wants (e.g., when A wants a good owned by B, but has no good that B wants she uses money); (2) it is valued for providing a convenient way to trade and reduce transactions costs; (3) it carries default penalties, i.e., one is penalized for owing money; (4) value is supported by high enough dynamic expectations[4]; (5) it's issue is controlled by an outside bank;[5] and (6) Money serves as insurance against economic fluctuations (see Bewley (1986), Karatzas et al. (1984)).

Monetary theory is a complex topic involving economic optimization, expectations, trust and institutional considerations. The economic dynamics of money is often supported by several mechanisms that can be used to achieve the same ends. Here we consider the presence of an outside bank, acceptance of money in payments, and a default penalty on unpaid debt. This game has the property that the economy is able to substitute a nearly costless symbol of trade for an intrinsically valued commodity such as gold in the financing of transactions. From the observations noted above we know that a bank is not necessary but is sufficient to achieve this result.[6]

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[3] A bankruptcy or default penalty is required to insure against strategic default. The penalty (which need not be economic, such as going to debtors' prison) must be sufficiently unpleasant to act as deterrence.

[4] For example, they might believe that prices will be stable in a booming economy in the future.

[5] Without going into technical details, for (3) if an individual has the strategic opportunity to default he will do so unless there is a sufficiently high penalty for doing so. This penalty is typically denominated in some form of disutility or loss related to the money value of the loss. Item (5) is covered in this paper. For (4) see Grandmont (1983) for analysis of the role of expectations in supporting the value of money.

[6] A modern monetary economy has much of its complexity reflected in the institutions and the laws that have evolved in the development of that society, thus assuming the existence of an outside bank is at least as reasonable as assuming trading based on pair-wise search. The former is better suited to the economies

We investigate the behavior of a minimal economy that includes an outside bank and a default penalty on unpaid loans.[7] We chose to address reasons (3) and (5) listed above, as both bank loans and default penalties exist in a functioning modern economy and it is straightforward to implement them experimentally. Although the theoretical results are derived only for time horizons with certainty, we check the robustness of the certainty model by including laboratory sessions in which time horizon is uncertain. The other reasons to support the existence of fiat money merit separate investigation, and are excluded from the scope of this paper. We view financial institutions and the related laws as consequences of social evolution through custom and design. A minimal game tends to capture the design more than it captures the evolution of an institution, as the time span of evolution is generally too long to replicate in the laboratory.

We consider a finitely repeated game in which any money held at the end is worthless. However there is a banking system that allows individuals to borrow in such a way that they can avoid ending the game with worthless paper. There are two treatments: the terminal period of the game is known in advance (1) with certainty, or (2) with some uncertainty. Individuals can borrow at an exogenously specified money interest rate, but must pay a default penalty for ending in debt. When the terminal period is known in advance with certainty the theoretical results of Dubey and Geanakoplos (1992) prove that the individuals can maximize their payoff by ending the game with zero money balances. When termination is uncertain some money will be held to insure purchase power if the economy continues as is shown by Bewley (1986). We investigate experimentally these theoretical observations

In an exchange economy where fiat money is utilized the price level will be determined by the relationship among the initial amount of money held by the traders, the length of the game, the natural discount rate β for intertemporal consumption, and the bank rate of interest ρ.

We compare the predictions suggested by theory (see Section 3) with data observed in laboratory economies populated by profit motivated human agents and

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we live in and the latter is better suited to studies in early economic anthropology. They answer different questions.
[7] Huber et al. (2010) define minimal mechanisms as those which are stripped of details and retain only the basic features necessary to be playable in the laboratory.

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minimally intelligent (MI) algorithmic traders (specified later in detail) simulated on a computer.

2. ON SEVERAL APPROACHES

McCabe (1989) studies the time path of trade in an economy with a finite horizon where it has no value at the end of the last period. The market structure is a clearinghouse. The backward induction predicted by rational expectations was not observed. Duffy and Ochs (1999) utilize a search theoretic model based on the work of Kiyotaki and Wright (19889) to study which of several commodities emerges as a money. Our approach is different from, but complementary with the abovementioned experiments. We take as given the existence of two markets and a rudimentary central bank. The model is openly stacked and simplified in order to set up conditions conducive to rational expectations. In order to minimize the number of decisions we employ the sell-all organization of market, thus depriving the players of strategic action concerning sales.[8] We provide endowments of $(0, a, m)$ and $(a, 0, m)$ to make sure that there is strong incentive to purchase both goods. The so-called "cash-in-advance" condition is implicit in any simultaneous move model of price formation.

Since the money becomes worthless after the final period, at first glance it would appear that in the last period individuals will just bid all of their money and end up with useless money. With the ability to borrow and pay back after the last trade ending with money one has on hand is not an equilibrium solution. An individual will find it in her self-interest to borrow to the point that the income she receives after the last active market is just sufficient to cover the amount (principal and interest) owed. This, in essence, shifts the purchasing power of that income earlier in time and permits that individual to buy more in the last period. If all individuals consume all their income to pay off their debt after the final period prices will go up but there will be an equilibrium

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[8] Huber et al. (2010) examine the properties of three minimal market mechanisms—sell-all, buy-sell, and double auction—in full feedback general equilibrium settings. Here we use the first and the simplest of the three mechanisms because it cuts down on the number of decision variables and gives a simpler game than the buy-sell model. We settled for simplicity although the buy-sell model would have been better for two reasons. (1) With the sell all model trade is Pareto optimal; with buy-sell it fails to be Pareto optimal due to a wedge in the prices caused by the cash-in-advance condition. (2)Without the outside bank the Hahn paradox would hold; this is not so for the sell-all model trade takes place at the last period but the left over income is of no value. This is changed in both models when there is the opportunity to borrow.

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in which no money is held by the traders at the end as all income is consumed in paying off debt. This includes the initial issue of fiat money. Thus the finite economy must be "cash consuming" and for any finite length of trade and any positive rate of interest this will be true.[9]

3. BASIC THEORY

Consider an economy with two types of traders, who can trade two goods for money. One type of trader has an endowment of $(a, 0, m)$[10] and the other has $(0, a, m)$, where $a, m > 0$. In this economy, the traders of each type may borrow from a single bank at an announced rate of interest and then bid for the two available goods. The bank stands ready to lend a one-period loan to anyone at a fixed rate of interest $\rho > 0$.

The individuals can pay the loan back at the beginning of the following period, or roll a part or all of the unpaid balance and interest over and add it to the next period's loan. One can only go bankrupt at the end where any outstanding debt is charged against the trader's total earnings from the entire game.

Even at this level of simplicity several basic issues arise. Should the bank be a strategic player or a dummy? We have chosen it to be a dummy. Does it fix in advance the quantity of money to be lent, or the interest rate to be charged, or fix both as its modus operandi? As the bank is a dummy we have chosen to specify an interest rate as a parameter in the game. We implicitly assume that the bank always has sufficient funds to lend, and thereby avoid having to discuss the details of the meaning of bank reserves. The bank permits the loans to be rolled over. The roll over condition is an important feature in finance that enables borrowers to delay any day of reckoning by replacing a current constraint with a future one.

For simplicity we stipulate that any positive money balances carried from one period to the next do not earn any interest.[11] A more general game would permit traders to deposit in, as well as borrow from, a bank thereby earning returns on any surplus

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[9] If we consider the infinite horizon with interest rate $1+\rho = 1/\beta$ in this never ending economy. The role of the bank, lending and final settlement disappears. Paradoxically the stationary state for the infinite horizon is as though the roles of time, money and the bank have disappeared in this instance. In contrast, for finite length of the economy and positive rate of interest, there is no pure stationary state.

[10] That is, a units of good A, 0 units of good B, and m units of money.

[11] Historically in U.S., real deposit rates have been close to zero, while historical interest rates on loans have been positive.

financial capital. In the model economy, we limit the players to borrowing for two reasons. The first is to keep the game as simple as possible by defining a smaller choice set for players, i.e., confining their financial decision to the amount of borrowing instead of the amounts of borrowing and depositing. The second reason is that in illustrating the value of paper money that has no given positive terminal value we need to investigate the behavior of the players at the terminal points and to compare it with the predictions of a finite period dynamic programming model of trade with a specified salvage value condition.

The experiment requires that the individuals make two types of decision, a financial decision to borrow an amount d and a market decision to bid amounts b_i with i =$1,2$ for each of the two goods. This game is known as the "sell-all" game where all individuals put up for sale their entire endowment of goods.[12] For the sell-all game of T periods the utility function of the traders is given by

$$\sum_{t=1}^{T} \beta^{t-1} 10\sqrt{x_{it}\, y_{it}} + \beta^{T} \mu \min[m_{iT+1}, 0]$$

where β is a natural time discount rate for consumption, $10\sqrt{}$ is the utility function for a level of consumption of x_{it} units of good A and y_{it} units of good B during period t, and μ is the penalty for bankruptcy (i.e., holding a negative cash balance at the end of the game in period T). This enables us to obtain closed form solutions for borrowing, bids and prices in the first and the subsequent periods. They are:

$$b_1 = \frac{(1+\rho)^T m}{2(1+\rho)^T \frac{(1-\beta^T)}{1-\beta} - 2(1+\rho)^{T-1} \frac{(1-\beta^T)}{1-\beta}} = \frac{(1+\rho)(1-\beta)}{2\rho(1-\beta^T)} m$$

and

$$p_1 = \frac{2b_1}{a} = \frac{(1+\rho)(1-\beta)}{2\rho(1-\beta^T)a} m$$

with the inter-period linkages given by:

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[12] In a closely related and somewhat more complex "buy-sell" game (see Huber, et al. 2010, and Shubik 1999) individuals make an additional decision q about the amount of their endowed good they offer for sale. Much of the current paper is limited to results from the simpler sell-all game. The mathematical derivations are given for the two games are given in Quint and Shubik (2008); their empirical properties in laboratory environments are reported in Huber et al. (2010a).

$$b_t = (1+\rho)^{t-1} \beta^{t-1} b_1$$
$$p_t = (1+\rho)^{t-1} \beta^{t-1} p_1$$

and finally

$$d_t = \frac{(1+\rho)^{t+1}}{\rho} \frac{1-\beta^t}{1-\beta^T} m - \frac{(1+\rho)^t}{\rho} \frac{1-\beta^{t-1}}{1-\beta^T} m - (1+\rho)^t m$$

There are T time periods, followed by full settlement at the beginning of period $T+1$. In the finite games one may set β such that $0 < \beta \leq 1$. In order to preserve the boundedness of the payoffs in infinite horizon models, $0 \leq \beta < 1$. Zero expected monetary inflation requires the Fisher condition $1+\rho = 1/\beta$ to hold. If exogenous uncertainty is present in the economy, the noninflationary condition must be replaced by a somewhat more complex condition (see Karatzas et al. 2006).

In the above expressions we note a considerable simplification when $1+\rho = 1/\beta$,
$$b_t = b_1, \ p_t = p_1, \text{ and } d_t = \beta^{T-t} m/(1-\beta^T).$$

In the experiment it is specified that at the termination of play after settlement of debt, any positive amount of money retained by the traders is of no value and any unpaid debt is of negative salvage value which is subtracted from the payout to the players. Zero worth of positive money balance at the end of the last period retains the intrinsic property of fiat money; negative value of any unpaid debt at the end is essential for a debt covenant to have any force.

In actual economic life the length of the lags in payments and delivery of goods varies considerably. Lags are possible in delivery of both money and goods. For the sake of simplicity we assume that the goods traded arrive in time to be utilized in the same period in which they are traded and payments are delayed until the following period.

When the periodic endowments of the individuals are given by $(a, 0)$ and $(0, a)$ and the initial amount of money endowed to each agent (only at the beginning of period 1) is m, Quint and Shubik (2008) show that the competitive market price of the goods at time t is given above together with the amount borrowed and the bid.[13]

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[13] There are many variants and extensions of this model that merit investigation but are not covered in this experiment. Much of the basic theory has been explored by Bennie (2006) who derives explicit formulae for cyclical endowments. This calls for models with a bank that makes loans as well as accepts deposits.

4. THE EXPERIMENTAL SET UP

In this experimental study we want to explore the influence of several variables on market outcomes like price level, price path, and efficiency. We therefore vary:

(1) The *number of periods* (10 or 20)

(2) The *natural discount rate β* (1, 1/1.05, 1/1.15), resulting in theoretically predicted price paths that are increasing ($\beta=1$), flat ($\beta=1/1.05$) or decreasing ($\beta=1/1.15$). We keep the interest rate (ρ) fixed at 0.05 throughout except in one session in which it is 0.15.

(3) *Whether subjects know the number of periods* for sure (most treatments) or with some uncertainty (robustness check, labeled with an added "_u").

(4) *Experience* of subjects, i.e., in several treatments we let subjects play a second and sometimes third round of the same game to examine if additional subject experience affects the performance of the economy.

We conducted 11 different treatments with a total of 23 experimental runs (see Table 1).

(Insert Table 1 about here)

In all our treatments, we fixed parameters $a = 200$, $\rho = 0.05$, and $m = 1,000$. In five treatments we used $T = 10$, while for the other six treatments we used $T = 20$ to explore the effect of varying the number of periods. We also varied the natural discount rate β: with $\rho = 0.05$, depending on the value of β the theoretically predicted equilibrium price path is inflationary ($\beta = 1$), flat ($\beta = 1/1.05$) or deflationary ($\beta = 1/1.15$). We label our treatments after this theoretical price path (INFL, FLAT, and DEFL, respectively), the number of periods (10 or 20) and whether the number of periods was exactly known

to subjects or only known with some uncertainty (the latter have "_u" for uncertainty added to the treatment name.[14]

The resulting treatments are INFL_10 and INFL_10_u, INFL_20 and INFL_20_u for the treatments where increasing prices are predicted. We have FLAT_10, FLAT_20, and FLAT_20_u where prices should be flat according to theory. Finally we ran DEFL_10, DEFL_10_u, and DEFL_20 for cases where the natural discount rate was higher than the interest rate (see overview in Table 1 for details).[15]

To check the robustness of our results we conducted one additional run with a higher interest rate of 15 percent. Specifically, $a = 200$, $\beta = 1/1.15$, $\rho = 0.15$, $m = 1,000$, $T = 20$. As $\beta(1+\rho) = 1$ the predicted price path is flat and following our usual nomenclature we labeled this treatment FLAT_20_rho_15%. Results for this treatment are presented at the end of the paper.

4.1. Experimental implementation

All treatments were conducted in the same way: subjects were seated in front of a computer, separated from all other subjects by sliding walls. Communication among subjects was not permitted. Written instructions (see Appendix A) were read out aloud and any questions were answered privately. A questionnaire tested whether subjects had understood the instructions. The experiment was conducted and subjects' earnings were paid to them in cash individually.

In each run ten subjects traded two goods labeled A and B, for money. Five of the ten subjects were endowed with ownership claim to 200 units of A and none of B, while the other five had ownership claim to 200 units of B and none of A, at the beginning of each period. "Ownership claim" means that they received as income the proceeds from the sale of 200 units of the good they were endowed with, but they had no control over these 200 units – all units were automatically sold each period. Each subject had the same

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[14] The extent of uncertainty was given in the instructions as 8-12 periods in the 10-periods case and 15-25 periods in the 20-period case. However, actual period numbers were 10 and 20 periods, except for one run of 18 periods.

[15] To check the robustness of our results we conducted one additional run with a higher interest rate of 15 percent. Specifically, $a = 200$, $\beta = 1/1.15$, $\rho = 0.15$, $m = 1,000$, $T = 20$. As $\beta(1+\rho)=1$ the predicted price path is flat and the treatment is thus labeled FLAT_20_rho_15%. Results for this treatment are presented at the end of the paper.

starting endowment of money $m = 1,000$ at the beginning of period 1. The interest rate for loans (ρ) was fixed at 5 percent per period in all treatments.[16]

All goods are consumed at the end of each period with no balances of goods A and B carried over from one period to the next; endowments of goods are reinitialized at the start of each period. Money holdings (positive and negative) are carried over to the following period.

The trading mechanism is a simple call market in which all endowments of goods are automatically sold each period. All traders submit two numbers for the amount of money they bid to buy goods A and B. The maximum amount a trader can bid is the sum of his beginning-of-the-period money holdings plus the loan he takes out from the bank – this amount was unlimited. To derive the price for A the sum of all bids for A is divided by the total number of good A in the market (5 times 200 = 1,000) by the computer. The same is done for B. Traders endowed with A receive as income 200 times the price of A, and analogously for those endowed with good B.

Each period the ending money balance of each trader equals his starting money balance minus the amount of money tendered for the two goods plus the income from selling his 200 endowed units of either A or B minus interest on any loan. Money holdings influence earnings directly only in the very last period of the session when negative money holdings are divided by four and deducted from the total points earned. Positive money holdings at the end of the session have no value and are discarded.

In each period the traders can earn points that are converted to dollars (or euros) at a pre-announced exchange rate at the end of the experiment. Specifically

$$\text{Points earned} = 10 \cdot \sqrt{x_{ij} * y_{ij}} \cdot \beta^{Period-1}$$

with x_{ij} and y_{ij} the number of units of A and B bought in a period. The last term with β is the discount rate of points and with $\beta<1$, points earned in later periods are not as valuable (in take home dollars or euros) as points earned in the beginning. β is thus the main variable to distinguish our treatments, as it defines the theoretical price path. By varying the value of β, we chose $(1+\rho)\beta$ to be greater than, less than or equal to 1 so as to expect to encounter inflation, deflation, and a steady price level in the respective treatments. In

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[16] As mentioned earlier, we conducted one treatment where the interest rate was set to 15 percent. This is labeled FLAT_20_rho=15%.

INFL_10 and INFL_20, with 10 and 20 periods respectively, $\beta = 1$, and therefore $(1+\rho)\beta = 1.05$, theory predicts inflation. Theoretically the rate of inflation should be lower in the longer treatment INFL_20.

In Treatments FLAT_10 and FLAT_20 the term $(1+\rho)\beta$ equals one, which theoretically should yield flat prices. Finally, in Treatments DEFL_10 and DEFL_20 $(1+\rho)\beta = 1.05/1.15 = 0.9134$, which should result in deflationary price paths. In these treatments loans and prices should be highest at the beginning, when many points can be earned.

Four of the six treatments are then also conducted with uncertainty of the time horizon, i.e., instead of knowing the exact number of periods subjects only learned that the experiment would run for either 8-12 periods or 15-25 periods.

Experience can be expected to play a role in such an environment. Four of the treatments (INFL_10, INFL_20, FLAT_20, and DEFL_10) were therefore repeated once (for 20-period runs) or twice (for 10-period runs) with the same cohort of subjects in contiguous interval of time.[17]

All treatments were conducted with software written using z-Tree (Fischbacher 2007). Six of the runs were conducted at Yale University while the other runs were conducted at University of Innsbruck. Each run took between 60 minutes (10-period markets) and 90 (20-period markets) minutes. Average payments were \$22 at Yale and €18 in Innsbruck. While most subjects had participated in experiments in economics before, no student participated in more than one of the treatment of the type presented in this paper. However, four of the treatments were repeated with the same subjects to explore any effects of experience and learning on market outcomes.

Note that all treatments are cash consuming. This means that all of the initial endowment m per capita of government money does not remain available for transactions because it gets used up for interest payments on borrowings from the bank in the finite horizon game[18]. As the horizon gets longer, the size of the equilibrium initial borrowing drops, and so do initial prices (see Tables 2 and 3).

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[17] The procedure in the lab was to carry out the first run, then pay out subjects in real money, then carry out the second run, pay subjects out again, and then carry out the third run (in the case of a 10-period setting).
[18] An infinite horizon model has no termination and hence no worthless assets are left over. This feature raises accounting problems. Essentially fiat money is the only financial asset that does not obviously have

4.2. General equilibrium benchmark: oligopolistic behavior

When the number of players is small, the difference between the predictions of competitive and non-cooperative equilibria is relatively large. However, with 10 players, that difference in earnings is of the order of 0.5 percent. Since that is not the main subject of investigation in this paper, it is reasonable to use the competitive equilibrium solution as a benchmark for comparing the experimental results.

4.3. Market with Minimally Intelligent (MI) Agents

We examine the behavior of this economy with an outside bank when it is populated by minimally intelligent (MI) algorithmic agents who follow simple myopic pre-specified decision rules. The purpose of this examination is to learn the extent to which the properties of the outcomes of this economy may follow from its structure and are robust to behavioral variations of the agents. This allows us to compare and contrast the outcomes of experimental market games against two benchmarks: first, the competitive equilibrium derived from assumption of optimization by individual economic agents, and second the outcome from markets populated by minimally intelligent agents who randomly pick their choices from their bounded opportunity sets (see Gode and Sunder, 1993). Here we face a somewhat more difficult problem of choosing the minimal abilities required to operate in multiple markets for goods and credit.

For implementation of minimally intelligent agents in this economy, several considerations are relevant. First, such agents need external constraints on the domain from which they can choose their actions. Second, these agents do not anticipate the future, and thus their actions are not influenced by consequences that might be foreseeable by more intelligent agents with powers of anticipation. Finally, they choose their actions randomly from the opportunity set available to them. Note that the behavior of an economy that has no value for residual money balances and includes a debt market

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an offsetting debit held by another individual in an economy as portrayed by general equilibrium theory. In order to obtain the balance government has to be introduced as a recognized agent.

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and is populated with such myopic investors should be expected to differ significantly from the operation of an economy with intelligent agents who can anticipate the future including the possibility of default and its consequences (e.g., bankruptcy penalty) when debt is available. While these considerations are not unique, they appear to be a reasonable start. It is relatively straightforward to investigate the consequences of alternative specifications of such agents.

We specify the minimally intelligent agents as follows: (1) at the beginning of each period, they choose their total spending on goods A and B as a random number drawn from a uniform distribution U(0, max(0, (Beginning cash balance + credit limit))), where the beginning cash balance is *m* in period 1; in the subsequent periods, it is the cash from the sale of the endowed good (A or B) minus any borrowing and interest on that borrowing in the preceding period. The max function ensure that if the beginning cash balance is more negative than the credit limit, spending of the agent during that period must be zero. Unlike intelligent agents, these minimally intelligent agents do not anticipate the penalty associated with outstanding debt at the end of the final period. Finally, the total spending chosen is split between goods A and B using a randomly drawn fraction distributed uniformly U(0, 1). The agents are unintelligent borrowers; if credit is available they may take it much like a subprime borrower with little anticipation or even understanding of the future. Credit limitation rules of good banking prevent them from overloading on loans and their consequences. The extra intelligence in a responsible bank may thereby make up for any shortfalls in the individual borrowers.

As far as possible the parameters of the economies simulated with MI agents were set the same as in the human session described above. Thus the cash endowment in period 1 is fixed at 1,000 for all agents. The market is also populated with five traders of each of two types with complementary consumption good endowments of (200, 0) and (0, 200) respectively. In human subject economies, there is no limit on the amount of borrowing; in MI economies, subjects must borrow enough money to bring any negative cash balance at the beginning of the period to zero, and if their beginning of the period cash balance is positive, they borrow an amount equal to a uniformly drawn random number between zero and the beginning cash balance discounted by interest for one period times a fixed multiplier (we used multiplier 1). The interest rate (5 percent), payoff

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multiplier (10), payoff exponent (0.5, i.e., the square root), and penalty multiplier for unpaid loans (0.25) are all set as in the human experiment. We report the results of the same three different natural discount rates as in the experiment with humans (0, 5 and 15 percent).

5. RESULTS

Although the rules of the game are simple, the considerations of the terminal conditions, price and borrowing behavior call for a sophisticated strategy. Our concern in this section is to examine the correspondence, or lack thereof, between various aspects of the theoretical predictions of general equilibrium (GE) model, and the observed outcomes of these economies. In Section 5.9 we will also explore how efficiently the markets function when they are populated with minimally intelligent agents as defined above. We focus on the development of prices, loans, money holdings, and efficiency.[19] In addition, the effects of an uncertain time horizon and of experience are explored.

5.1. Price paths and price levels

Equilibrium predictions for price paths are different for the six treatments. GE predicts inflationary prices in the INFL-treatments, stable prices in the FLAT-treatments, and falling prices in the DEFL-treatments (see Table 2 for an overview of GE price predictions). Figure 1 shows the realized and equilibrium price paths for ten treatments.[20]

(Insert Figure 1 about here)

We see that in each run the slope of price paths conform to the theoretical GE prediction, i.e., we observe inflation in the INFL treatments (two panels in the top row), relatively stable prices in the FLAT treatments (two panels in the middle row), and price decreases in the DEFL treatments (two panels in the bottom row). The coefficients of linear regressions of prices over time (periods) are presented in Table 4.

(Insert Table 4 about here)

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[19] The control treatment FLAT_20_rho_15% will be briefly discussed towards the end of the paper and is presented in Figure 7.
[20] Treatments that are identical except for the certainty/uncertainty of time horizon are shown in the same panel to save space and allow easier comparison of results. Only the average of the prices of goods A and B in each period is shown to avoid overcrowding (the differences between the prices of goods A and B are not statistically significant in any of the 23 runs).

The coefficients are all positive for each run and each good in the INFL treatments, and 15 of the 18 coefficients are statistically greater than zero at 1-percent level of significance. In the FLAT-treatments 8 coefficients are positive, 4 are negative, and none is statistically different from zero at 1-percent level; one is (marginally) significantly positive, the other is negative (t-values between -2.01 and 2.03). In the DEFL-treatments all 14 coefficients are significantly negative (t-values of -4.54 or less). Conformity of the slopes of empirical and theoretical GE price paths implies that these economies empirically conform to this important prediction of the model over variations of discount rate β.

Price levels, on the other hand, exhibit significant deviations from the respective GE predictions: in the 10-period treatments 9 of 12 runs show prices below the level predicted by GE. Only the three runs (of the same cohort of subjects) of DEFL_10 show prices above the GE-levels until the last few periods. Prices in the 20-period treatments track the GE predictions more closely, with the exception of the INFL_20-treatments where prices are on average about 20 percent too high. On the whole, the GE levels appear to form a reasonable anchor for the general tendency of prices in these economies.

5.2. Borrowings

In all treatments subjects could borrow without limit at an interest rate of 5 percent per period. With the amount of money fixed at 1,000 per subject in period 1 (and declining by the amount of interest payments in the subsequent periods) the level of borrowing determined the quantity of money in the market, and thus the price levels. The evolution of borrowing is closely reflected in the evolution of prices. In GE, the average size of borrowing increases in the INFL, increases at a slower rate in FLAT treatments, and decreases gradually in DEFL treatments (see Table 3 for numerical predictions). Figure 2 shows that the general patterns predicted by GE are present in the experimental data with borrowing increasing in all runs of the INFL and the FLAT treatments, but decreasing in the DEFL treatments. This holds irrespective of the length and uncertainty of time horizon.

(Insert Figure 2 about here)

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GE predicts higher borrowing in the 10-period economies than in the corresponding periods of the 20-period economies (see Table 3). Experimental data also reflect this feature of equilibrium predictions: borrowings in INFL_10 were on average 44 percent higher (1,944 vs. 1,354) than the respective numbers during the first ten periods of INFL_20 (GE-prediction: 2,000 vs. 371). Similarly, average loans in the first 10 periods of FLAT_10 are 147 percent higher (1,712 vs. 694) than those of FLAT_20, again in line with theoretical predictions (GE-prediction: 2,000 vs. 761). In the deflationary treatments theory suggests higher loan levels in the 10-period market in the first ten periods and the data support this prediction as well with 4,168 in DEFL_10 vs. 1,442 in DEFL_20 (GE-prediction: 2,000 vs. 1,354).

We conclude that trends and relative levels of borrowing in these markets populated with profit-motivated human agents are largely consistent with the theoretical predictions (with the exception of three DEFL_10-runs).

5.3. Money Balances

The GE prediction for all treatments is that money holdings are zero after the last period. However, reaching the exact GE-prediction requires multi-period backward induction and a high degree of coherence or cooperation by subjects. As communication between subjects was strictly forbidden such deliberate cooperation was not possible.

Money holdings in the economy are depleted through interest payments at a rate determined by the volume of borrowing. With sufficiently high borrowings, money balances can turn negative. Figure 3 presents the development of average money holdings over time in the ten treatments.

(Insert Figure 3 about here)

In all treatments average money holdings must decrease because the economy is cash consuming by design. Especially in the FLAT-treatments most runs end in the proximity of zero average money holdings, arguably because the "task" for subjects was easiest in these treatments, compared to more demanding INFL- and DEFL-treatments.

In some of the other treatments we observe strong deviations – overspending in all runs of DEFL_10 and INFL_20. In DEFL_10 this is driven by heavy overspending, as subjects, trapped in a prisoners-dilemma-like situation, try to buy large quantities of

goods in the first few periods by taking out large loans. As a consequence the initial money endowment of 1,000 is eaten up by period 5 (run 1) or 4 (runs 2 and 3), and the average money holdings turn negative. Loan levels drop in later periods, but just rolling-over existing loans leads to further reductions in money holdings. In INFL_20 subjects seem to underestimate the effect of the length of the experiment – in period 10 average money holdings are still strongly positive in all runs, turning negative between periods 13 and 17 and falling ever-faster, as subjects take higher loans to get rid of positive money holdings in later periods.

Our data reveal that the money balances in these economies are affected by their length as predicted by the GE equilibrium. Table 5 gives average money holdings after period 10, separated for the 10-period and 20-period economies. 10th-period holdings in the 20-period-treatments are on average 467, i.e., roughly half of the initial endowment, while they are on average -159 in the 10-period markets. Money holdings after period 10 are positive in every single run of 20-period-treatments, while they are negative in five of twelve runs of 10-period-markets.

<center>(Insert Table 5 about here)</center>

Money holdings yield a good proxy for the "rationality" of decision making by subjects: traders may decide to keep some of their money unspent for various reasons. However, loans have a cost in the form of interest payments, and unspent money earns no interest. Therefore, it is never rational to take a loan and then not spend all of the money. We compute for each participant the percentage of money left unspent in each period, and calculate the respective averages across traders who do and do not borrow. Table 6 shows that on average borrowers kept only 3.3 percent of their total money balance unspent, while the non-borrowers kept 15.8 percent unspent. This difference pattern is present in every one of the treatments.

<center>(Insert Table 6 about here)</center>

To gain further understanding of money balances, we also calculated the percentage of money unspent for each period of each market and averaged this number across all treatments (separated for 10- and 20-period treatments). The respective averages are shown in Figure 4. Over the 10 or 20 periods of the runs, the average

amount of money left unspent tends to decrease steadily towards a plateau. The plateau is lower for the borrowers than for non-borrowers.

<div align="center">(Insert Figure 4 about here)</div>

Decrease in money balances likely reflects learning effects as well as the attempt to convert the money into units of consumption towards the end of the runs before it becomes worthless. To shed some light on this we calculated for each period the numbers of subjects taking a loan. This was done separated for INFL, FLAT, and DEFL-treatments. The results, presented in Figure 5, show at the start more loans are taken in the DEFL-treatments (where most points can be earned in the beginning) than in the FLAT-treatments, while the lowest number of loans is found in INFL-treatments. By the end of the markets this relation reverses, i.e., most loans are taken in FLAT- and INFL-treatments, while the lowest number is found in DEFL-treatments. This holds for 10- and 20-period markets and is in line with theoretical average loan predictions (see Table 3).

<div align="center">(Insert Figure 5 about here)</div>

5.4. Efficiency

Efficiency of these economies is measured by the total points earned by subjects as a percentage of the maximum possible.[21] Since the markets populated by minimally intelligent (MI) agents had the efficiency of 78.6 percent on average, presumably a consequence of the economy's structure (e.g., sell-all market, and multiplicative earnings function) even when for participating agents choose their borrowing and bidding randomly. In comparison, autarkic efficiency without any trading would be zero because each agent is endowed with 200/0 or 0/200 of the two goods.

In these laboratory experiments efficiency ranged from 71.1 to 100 percent for individual periods, and from 95.2 to 99.2 percent for individual economies. Efficiency of economies populated with profit-motivated human agents is considerably higher than for markets populated by MI-agents, suggesting that some 20 percent gain in efficiency arises from the human subjects' actions to seek higher earnings. Figure 6 shows that these high levels of efficiency appeared within the first few periods with little subsequent

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[21] This maximum is 1,000 points per period in INFL-treatments, as the natural discount rate is 1. In FLAT- and DEFL-treatments the number of points that can be earned is 1,000 in the first period, and decreases in subsequent periods.

improvement. There is some evidence for learning in periods 1 and 2; in 16 of the 22 runs, efficiency in the last period is higher than in the first period.

(Insert Figure 6 about here)

Borrowing could drive earnings because borrowers have more money to buy consumption goods and earn points. This is evident in our data: Table 7 shows that borrowers earned 100.6 percent of equilibrium earnings while the non-borrowers earned only 89 percent on average.[22] We conclude that borrowers spent almost all of their money, bought more goods than non-borrowers, and earned significantly more.

(Insert Table 7 about here)

5.5. Length of time horizon: 10- vs. 20 period-markets

In each treatment subjects were endowed with 1,000 units of money. As this money mostly was (and should have been) "consumed" by interest payments, loans (and therefore prices) in shorter treatments are predicted by theory to be higher than in the corresponding periods of the longer treatments. In a 10-period economy, average borrowing of 2,000 would have incurred an interest cost of 100 points per period and would consume the entire initial endowment of money by the end of the 10th period. In a 20-period economy, on the other hand, it would take the interest payments on an average loan of 1,000 to exhaust the initial endowment of money by the end.

A comparison of prices in INFL_10_u and INFL_20_u (between the left and right column of panels in Figure 1) demonstrates the effect of the time horizon on the rate of inflation. Price levels in both treatments started at the same level, but increased faster in INFL_10_u, reaching an average of 19.34 by period 10 vs. only 9.20 in INFL_20_u. The data conform to the GE prediction of the effect of time horizon on the rate of inflation in this economy. Similarly, prices in FLAT_10 are on average 11.34 vs. only 7.65 in FLAT_20; this difference and its magnitude are also in line with theoretical predictions. For the deflationary treatments the theoretical predictions of price paths and levels hold as well, i.e., both are decreasing and prices are higher in the shorter treatment (average of 15.6 in DEFL_10 and DEFL_10_u vs. 7.14 in DEFL_20).

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[22] Note that in some of the markets earnings of more than 100 percent are achieved by borrowers. This can happen because these traders buy more goods and thus earn more points at the expense of non-borrowers who end up earning less than 100 percent of equilibrium earnings.

As discussed earlier, the length of the horizon also affected the money balances: at the end of the 10th period, money balances averaged -159 in 10-period economies; in the 20-period economies they were always positive and averaged 467 at that stage. However, by the end of period 20 average holdings in 20-period economies were -432 and were negative in seven of ten markets.

5.6. Uncertainty of Time Horizon

The theoretical GE benchmark has been derived only for economies with certainty of horizon. However, to check the robustness of the model in predicting the outcomes of these economies, we also conducted runs in which the subjects did not know the length of the horizon for sure. With the length of the horizon certain, it is possible for subjects to calculate how much money they can spend each period to exhaust their endowment at the end. This was not possible in INFL_10_u, INFL_20_u, FLAT_20_u, and DEFL_10_u. These treatments were identical to INFL_10, INFL_20, FLAT_20, and DEFL_10, respectively, but in the 10-period markets subjects only learned that the experiment would last between 8 and 12 periods, while in the 20-period markets subjects were told that they would trade for 15-25 periods.

This uncertainty complicates the decision process and should lead to lower spending of risk-averse subjects (to make sure they do not end with negative money balances if the experiment ran for 12 or 25 periods). We compare at the ending money holdings of treatments with and without uncertainty of horizons in Table 8.

<center>(Insert Table 8 about here)</center>

We see that in three of four cases (INFL_10, INFL_20, and DEFL_10) money holdings are higher for the uncertain than for the certain horizon. Only in FLAT_20 do we see the opposite – however, the difference of roughly 220 is smaller than any difference in the other three cases. Over all four treatments average money holdings at the end are -122 in the four treatments with certain horizon and 392 in the treatments with uncertain horizon. Thus, subjects seemed to be more careful, and thus thriftier, when there was some uncertainty of the time horizon. A logical consequence of the higher money holdings is that loans taken were on average lower and prices therefore lower when the time horizon was uncertain. Efficiency seemed not to be affected, as overall

efficiency is not significantly different with 97.5 percent with uncertain horizon vs. 98.0 percent with certain horizon.

5.7. Subject Experience

In several experimental studies experience has been shown to be an important driver of results, e.g., price bubbles in laboratory asset markets tend to disappear once subjects gain experience (see e.g. Smith et al. 1988, Dufwenberg 2005). We therefore ran some of our experimental markets with experienced subjects. Specifically, the second and third runs of INFL_10 and DEFL_10 were run with the same cohort of students, respectively, as in the first run of this treatment. Also in INFL_20 and FLAT_20 the second run was conducted with the same students, respectively, as the first run of these treatments.[23]

We find weak evidence for effect of learning on efficiency which is the same (in FLAT_20) or higher (in all other treatments) in the second and third runs than in the respective first runs in all four treatments where experienced subjects were used.

There is also weak evidence of effect of learning on prices and borrowing (approach to GE) in INFL_10, but quite the opposite in DEFL_10 where the first run was quite close to GE, but subjects then overspend, taking high loans to reap high earnings (points) in the first few periods, resulting in high prices in the beginning. In run 2 of DEFL_10 prices fell from 40.85 in period 1 (125% above GE) to 3.76 in period 10 (53% below GE). Thus, subjects understood how to maximize their earnings – by spending a lot in the first few periods and far less in the later periods. However, trapped in a prisoners-dilemma-like situation, they overspent in the first few periods and spent below optimum later).

In INFL_20 there is no evidence for learning, as we see two comparable runs close to GE but with higher prices and borrowing. The same holds for FLAT_20, where all results are very close to GE predictions.

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[23] The runs with one cohort of students were conducted on the same day, i.e. a given cohort of students was told during the instructions that they would play two (or three) runs of the same game. They then played the first run of a treatment and were then paid out privately in cash. Then the second run was conducted and again paid out privately. INFL_20 and FLAT_20, where one repetition was played were finished at that time. For INFL_10 and DEFL_10 a third run was played with the same cohort of students and then again paid out.

Overall we conclude that although there is significant evidence of learning across periods of individual run (which is common in most laboratory experiments), this learning seems to have reached a plateau by the end of most runs. There is only limited evidence of learning across runs when the same subjects continued to play in a second or third run. Since most markets are highly efficient from the start, repetitions lead to improvements roughly as often as to deteriorations (as measured by proximity of borrowing and prices to GE predictions).

5.8. Effect of a higher interest rate

As a robustness check we conducted an eleventh treatment. This is a replication of DEFL_20, but the interest rate is increased to 15 percent per period. With a natural discount rate β of 1/1.15 the resulting price path should be flat, with loans increasing slowly over time. The treatment is labeled FLAT_20_rho_15% and the single run we conducted, presented in Figure 7, confirms the theoretical predictions nicely and corroborates our earlier finding that especially the FLAT treatments come close to GE predictions.

(Insert Figure 7 about here)

5.9. Economies with Minimally Intelligent Agents

The MI markets, presented in most figures as a solid dark-grey line with bullet markers, perform more poorly than the corresponding human subject markets with respect to price levels, price paths, borrowings, money balances, and efficiency. MI-agents, as set up by us, do not take the natural rate of discount (β) into account in making their decisions. Therefore price paths, money holdings, and loan levels do not depend on β. Representative price, loan, money holding, and efficiency paths are shown in each panel of Figures 1, 2, 3, and 6. While humans did take β into account leading to observation of inflation, flat prices or deflation, respectively, in the appropriate sessions, there is no reason for such differentiation among paths in the MI agent simulations (and we chart the same simulation results in each column of panels in Figures 1, 2, 3 and 6). Prices decrease slowly over time, as interest on (randomly determined) loans depletes the money available to bid for the (fixed stock of) goods A and B. Similarly, loans decrease

slightly over time, irrespective of β, and as we chose a rather conservative credit limit that precludes the possibility of bankruptcy, MI-agents on average kept most of their initial money endowment until the end of the simulation (see Figure 3). As shown in Table 5 and in Figure 3, MI-agents on average still have 774 of their initial 1,000 cash after period 10, and 612 after period 20. This deviates strongly from GE predictions and from what we observe in our experiments with human subjects who get much closer to GE predictions.[24]

In Tables 6 and 7, presenting the percentage of money unspent and the earnings with and without loans respectively, no numbers are given for MI, as we defined our agents to spend all their cash each period and each agent takes a loan each period. The same is true for Figures 4 and 5.

We conclude that economies populated by minimally intelligent agents, as interpreted here, still reach a surprisingly high (75-80 percent) efficiency. However, their efficiency is still significantly lower than the level reached by humans. Insensitive to the influence of β, MI-agents are not able to produce the distinct price paths that GE theory predicts and experiments with humans produced.

6. CONCLUSIONS

In this paper we report that an outside bank and a default penalty are sufficient to ensure the value of fiat money in a simple laboratory economy. In addition we find that the markets populated by profit-motivated human subjects in our laboratory experiment yield outcomes that take the relationship of natural discount rate and interest rate into account to produce inflationary, flat, or deflationary price paths in line with theory. Market simulations with minimally intelligent agents, without faculties to anticipate the future, do not generate such distinct price paths. While simpler markets populated with such agents function reasonably well (e.g., Huber et al. 2010a), managing a borrowing relationship with a bank is more complex and requires additional faculties such as some elementary way to predict future states.

> **Comment [SS1]:** We need to link the conclusion to the purpose and introduction of the paper more strongly and explicitly. Perhaps the second (deleted) paragraph of the conclusion should be retained in some form. Also, Martin had drafted a new para pn April 5 which is not included here. SS

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[24] Other specifications of the MI agents, especially higher loan limits, would bring these markets closer to GE. However, we considered the chosen parameters to be reasonable interpretation of the concept of minimally intelligent agents.

Table 1: The experimental design*

(Interest rate $\rho = 0.05$ in all treatments except 0.15 in the last column)

	INFL_10 and INFL_10_u	INFL_20 and INFL_20_u	FLAT_10	FLAT_20 and FLAT_20_u	DEFL_10 and DEFL_10_u	DEFL_20	FLAT_20, $\rho = 0.15$
Periods	10	20	10	20	10	20	20
Natural discount rate	$\beta=1$	$\beta=1$	$\beta=1/1.05$	$\beta=1/1.05$	$\beta=1/1.15$	$\beta=1/1.15$	$\beta=1/1.15$
Predicted rate of price change	$(1+\rho)/\beta = 1.05$	$(1+\rho)/\beta = 1.05$	$(1+\rho)/\beta = 1$	$(1+\rho)/\beta = 1$	$(1+\rho)/\beta = 1.05/1.15 = 0.91$	$(1+\rho)/\beta = 1.05/1.15 = 0.91$	$(1+\rho)/\beta = 1$
Predicted price path	inflationary	inflationary	flat	flat	deflationary	deflationary	flat
Time Horizon known?	Certain and Uncertain	Certain and Uncertain	Certain	Certain and Uncertain	Certain and Uncertain	Certain	Certain
Experienced subjects?	Yes, in INFL_10	Yes, in INFL_20	No	Yes, in FLAT_20	Yes, in DEFL_10	No	No
Number of runs	INFL_10: 3 INFL_10_u: 2	INFL_20: 3 INFL_20_u: 2	2	FLAT_20: 3 FLAT_20_u: 2	DEFL_10: 3 DEFL_10_u: 2	2	1

*Experimental runs are labeled as follows: INFL, FLAT and DEFL for inflationary, flat and deflationary paths respectively, followed by the number of periods, followed by "u" for runs in which the time horizon was uncertain.

Table 2: Equilibrium prices for the six treatments with certainty of time horizon

(equilibrium predictions are the same for uncertain horizon when risk-neutrality is assumed)

Period	INFL_10	INFL_20	FLAT_10	FLAT_20	DEFL_10	DEFL_20
1	10.50	5.25	12.95	8.02	18.19	14.59
2	11.02	5.51	12.95	8.02	16.61	13.32
3	11.58	5.79	12.95	8.02	15.17	12.16
4	12.16	6.08	12.95	8.02	13.85	11.10
5	12.76	6.38	12.95	8.02	12.64	10.14
6	13.40	6.70	12.95	8.02	11.54	9.26
7	14.07	7.04	12.95	8.02	10.54	8.45
8	14.77	7.39	12.95	8.02	9.62	7.72
9	15.51	7.76	12.95	8.02	8.79	7.05
10	16.29	8.14	12.95	8.02	8.02	6.43
11		8.55		8.02		5.87
12		8.98		8.02		5.36
13		9.43		8.02		4.90
14		9.90		8.02		4.47
15		10.39		8.02		4.08
16		10.91		8.02		3.73
17		11.46		8.02		3.40
18		12.03		8.02		3.11
19		12.63		8.02		2.84
20		13.27		8.02		2.59

Table 3: Equilibrium loans for the six treatments with certainty of time horizon

(equilibrium predictions are the same for uncertain horizon when risk-neutrality is assumed)

Period	INFL 10	INFL 20	FLAT 10	FLAT 20	DEFL 10	DEFL 20
1	1,100	50	1,590	605	2,639	1,917
2	1,260	105	1,670	635	2,454	1,760
3	1,433	165	1,753	667	2,288	1,616
4	1,621	232	1,841	700	2,139	1,485
5	1,823	304	1,933	735	2,005	1,366
6	2,042	383	2,029	772	1,885	1,258
7	2,278	469	2,131	811	1,778	1,160
8	2,533	563	2,237	851	1,684	1,071
9	2,807	665	2,349	894	1,601	991
10	3,103	776	2,467	938	1,528	918
11		896		985		852
12		1,026		1,035		792
13		1,167		1,086		739
14		1,320		1,141		690
15		1,485		1,198		647
16		1,663		1,257		609
17		1,855		1,320		574
18		2,063		1,386		544
19		2,286		1,456		517
20		2,527		1,528		493

Table 4: Theoretical and Estimated Slope coefficients (t-statistics) in OLS Regressions of Price on Time

Certain horizon	Theory	MI Agents	Avg. for Humans	Run 1 A	Run 1 B	Run 2 A	Run 2 B	Run 3 A	Run 3 B
INFL_10	**0.64**	**-0.20**	**0.30**	0.41 (3.88)	0.42 (3.05)	0.04 (0.53)	0.05 (0.48)	0.57 (2.17)	0.29 (1.41)
INFL_20	**0.42**	**-0.20**	**0.45**	0.42 (7.54)	0.46 (11.66)	0.47 (14.46)	0.44 (8.16)		
FLAT_10	**0.00**	**-0.20**	**0.05**	0.06 (0.70)	0.02 (0.46)	0.11 (1.10)	0.01 (0.10)		
FLAT_20	**0.00**	**-0.20**	**-0.02**	-0.06 (-1.94)	-0.06 (-2.01)	0.02 (0.61)	0.01 (0.07)		
DEFL_10	**-1.12**	**-0.20**	**-3.24**	-2.05 (-5.58)	-1.46 (-4.54)	-4.41 (-20.53)	-3.96 (-13.42)	-3.66 (-12.96)	-3.92 (-11.46)
DEFL_20	**-0.61**	**-0.20**	**-0.51**	-0.46 (-25.72)	-0.50 (-19.96)	-0.55 (-14.67)	-0.54 (-13.15)		
Uncertain horizon	**Theory**	**MI Agents**	**Avg. for Humans**	Run 1 A	Run 1 B	Run 2 A	Run 2 B		
INFL_10_u	**0.64**	**-0.20**	**1.36**	1.77 (8.69)	1.68 (7.55)	0.98 (9.04)	1.00 (6.98)		
INFL_20_u	**0.42**	**-0.20**	**0.75**	0.74 (6.91)	0.68 (8.61)	0.77 (9.89)	0.82 (8.87)		
FLAT_20_u	**0.00**	**-0.20**	**0.02**	0.00 (0.12)	0.10 (2.03)	-0.01 (-0.58)	-0.01 (-0.20)		
DEFL_10_u	**-1.12**	**-0.20**	**-0.92**	-0.82 (-12.87)	-0.99 (-7.36)	-1.03 (-7.94)	-0.83 (-9.96)		

Table 5: Money Holdings at the End of Period 10

		Theory	MI agents	Avg. for Humans	Run 1	Run 2	Run 3
Certain Horizon	INFL_10	0	774	28	417	-34	-300
	INFL_20	794	774	323	395	251	
	FLAT_10	0	774	144	177	111	
	FLAT_20	614	774	653	622	684	
	DEFL_10	0	774	-1,084	-794	-1,321	-1,137
	DEFL_20	341	774	279	274	284	
Uncertain Horizons	INFL_10_u	0	774	302	112	491	
	INFL_20_u	794	774	580	452	708	
	FLAT_20_u	614	774	501	324	677	
	DEFL_10_u	0	774	185	346	23	
	Average 10 Certain	**0**	**774**	**-67**			
	Average 10 Uncertain	**0**	**774**	**244**			
	Average 20 Certain	**583**	**774**	**418**			
	Average 20 Uncertain	**583**	**774**	**541**			

Table 6: Percentage of Money Kept Unspent by Borrowers and Non-borrowers

(Averages across those periods when at least one trader was in the respective group)

		Percentage of money unspent by borrowers	Percentage of money unspent by non-borrowers
Certain horizon	INFL_10	8.4	37.6
	INFL_20	1.7	20.0
	FLAT_10	1.9	9.4
	FLAT_20	3.7	13.5
	DEFL_10	3.1	16.5
	DEFL_20	1.1	10.0
Uncertain Horizon	INFL_10_u	2.5	8.9
	INFL_20_u	7.3	12.3
	FLAT_20_u	2.8	14.4
	DEFL_10_u	1.0	15.3
	Average	**3.3**	**15.8**

Table 7: Efficiency: Average Points Earned per Period as Percentage of Maximum Possible for Borrowers and Non-borrowers*

(Averages across those periods when at least one trader was in the respective group)

		Percentage of maximum possible points earned by borrowers	Percentage of maximum possible points earned by non-borrowers
Certain Horizon	INFL_10	113.2	61.6
	INFL_20	104.7	89.8
	FLAT_10	102.9	87.6
	FLAT_20	103.4	91.8
	DEFL_10	97.2	93.1
	DEFL_20	97.9	98.9
Uncertain Horizon	INFL_10_u	104.3	85.1
	INFL_20_u	96.9	87.8
	FLAT_20_u	100.1	94.9
	DEFL_10_u	97.9	99.6
	Average	**100.6**	**89.0**

* Numbers above 100 percent are feasible because points can be earned by some traders at the expense of others.

Table 8: Money Holdings at the End, i.e. after 10 or 20 periods

Certain horizon	Theory	MI agents	Avg. for Humans	Run 1	Run 2	Run 3
INFL_10	0	774	28	417	-34	-300
INFL_20	0	612	-1,156	-1,005	-1,308	
FLAT_10	0	774	144	177	111	
FLAT_20	0	612	154	103	205	
DEFL_10	0	774	-1,084	-794	-1,321	-1,137
DEFL_20	0	612	-173	-207	-139	
Uncertain horizon	Theory	MI agents	Avg. for Humans	Run 1	Run 2	
INFL_10_u	0	774	302	112	491	
INFL_20_u	0	612	-880	-1,179	-580	
FLAT_20_u	0	612	-64	-334	207	
DEFL_10_u	0	774	185	346	23	
Average 10 periods certain	**0**	**774**	**-67**			
Average 10 periods uncertain	**0**	**774**	**244**			
Average 20 periods certain	**0**	**612**	**-392**			
Average 20 periods uncertain	**0**	**612**	**-472**			

Figure 1: Time series of prices (averages of goods A and B for each run) in the ten treatments with certain and uncertain time horizon compared to simulations with minimally intelligent (MI) agents and GE predictions
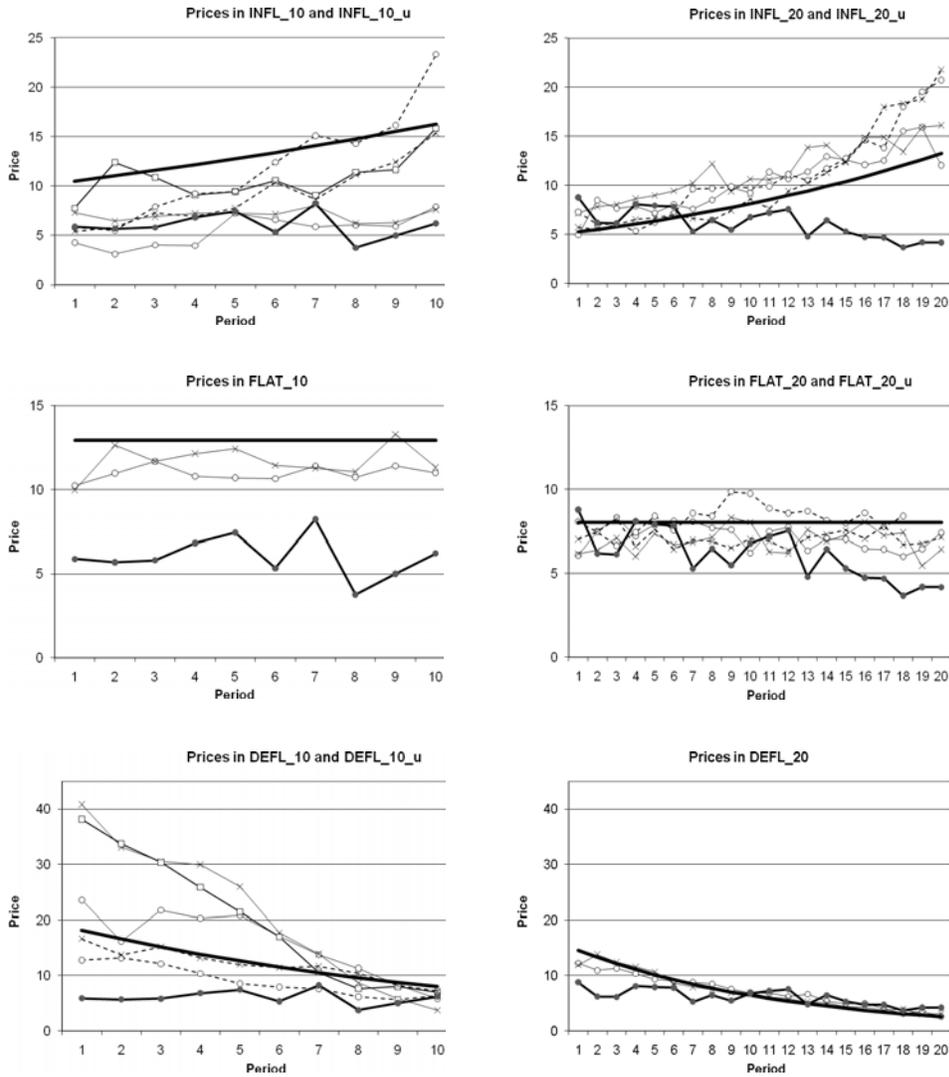
Figure 2: Time series of borrowings (average loans taken) in the ten treatments with certain and uncertain time horizon compared to simulations with minimally intelligent (MI) agents and GE predictions
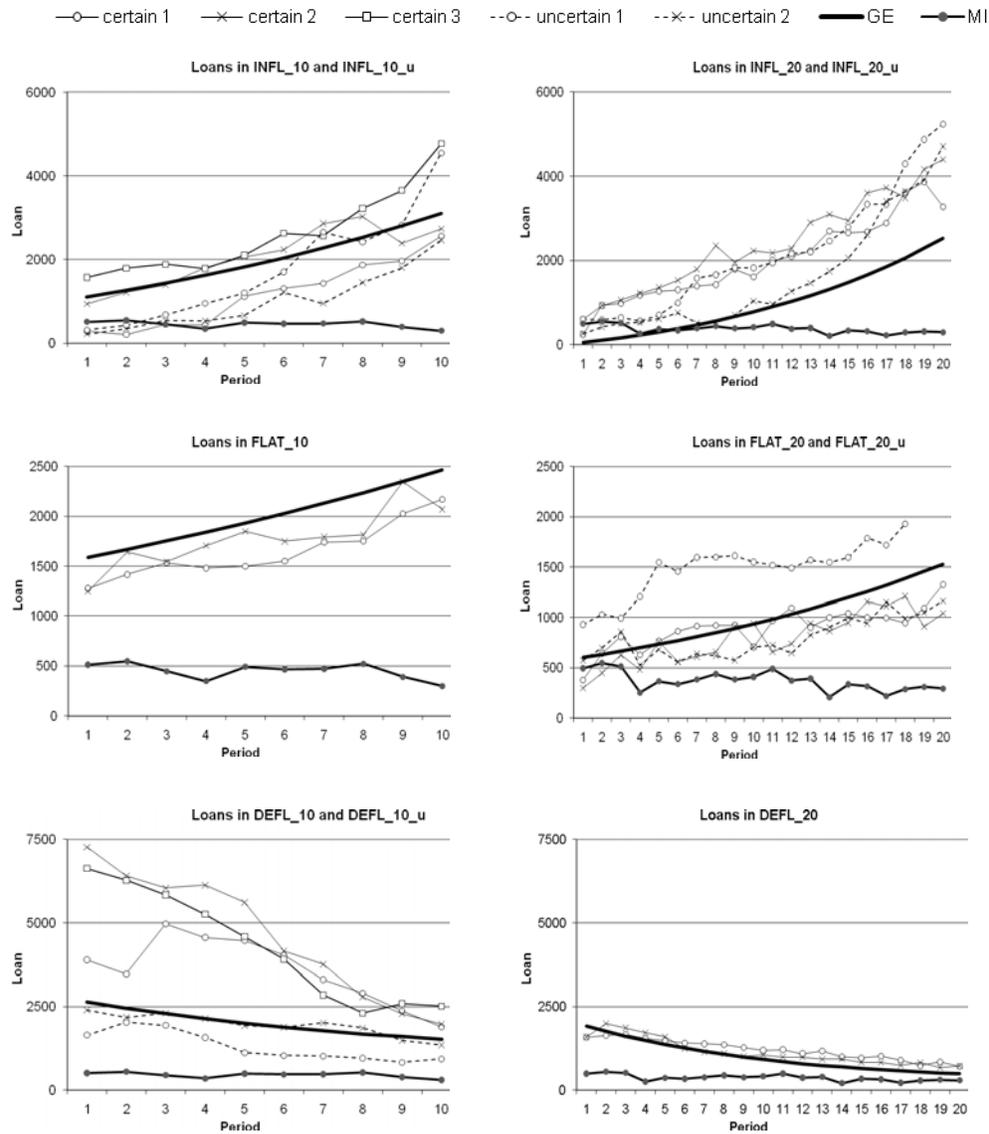
Figure 3: Time series of average money balances at the end of each period in the ten treatments with certain and uncertain time horizon compared to simulations with minimally intelligent (MI) agents and GE predictions
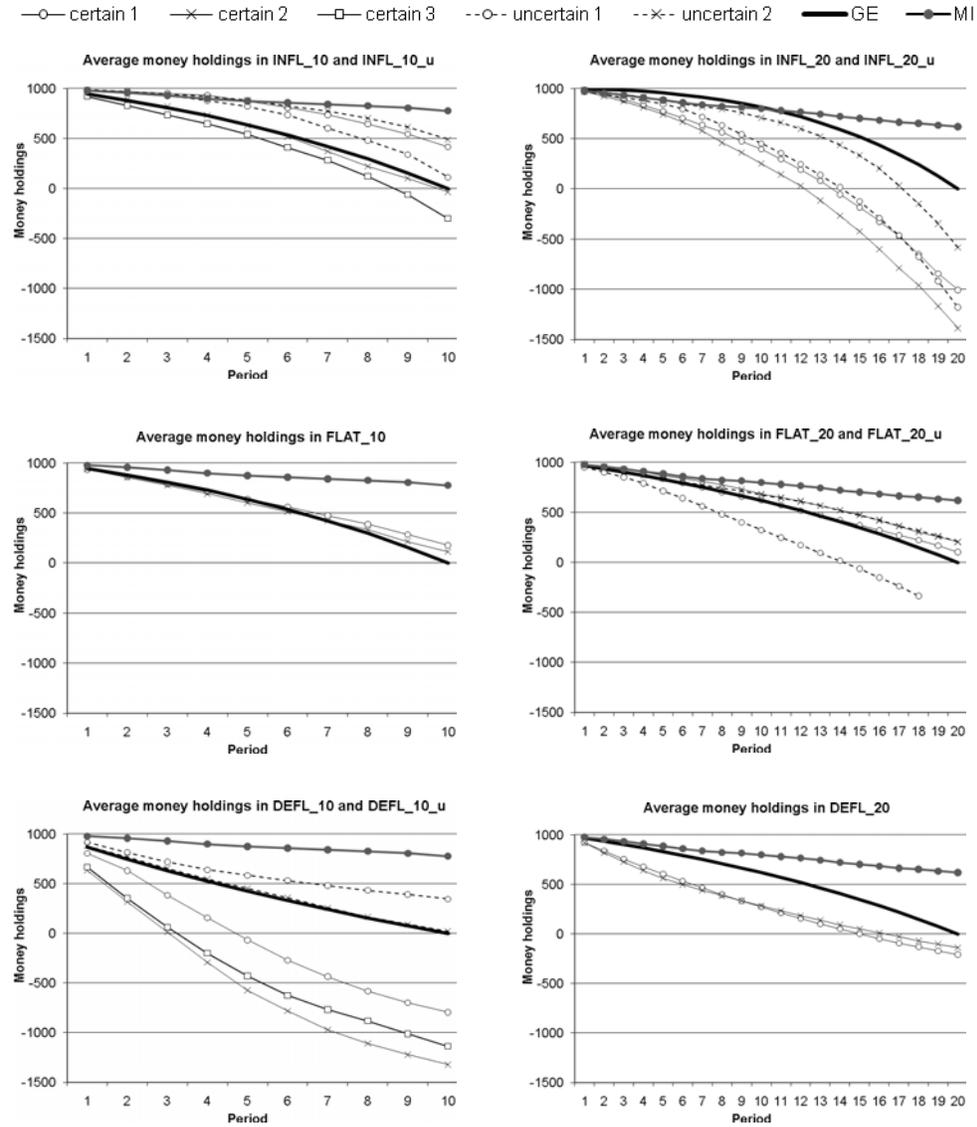
Figure 4: Average percentage of money kept unspent by borrowers vs. non-borrowers in the 10-period treatments (left) and the 20-period treatments (right)
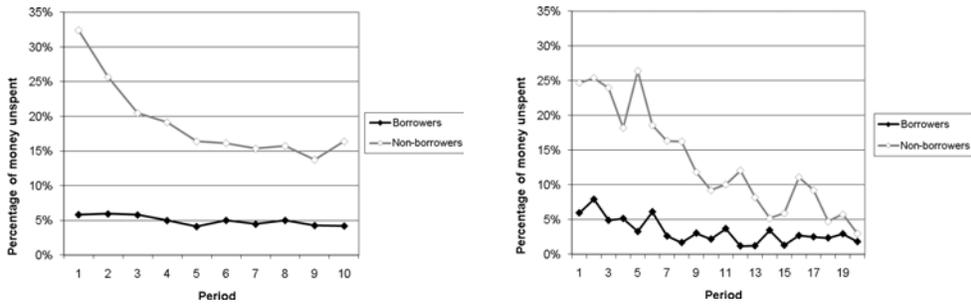
Figure 5: Average number of subjects taking a loan in the 10-period treatments (left) and the 20-period treatments (right)
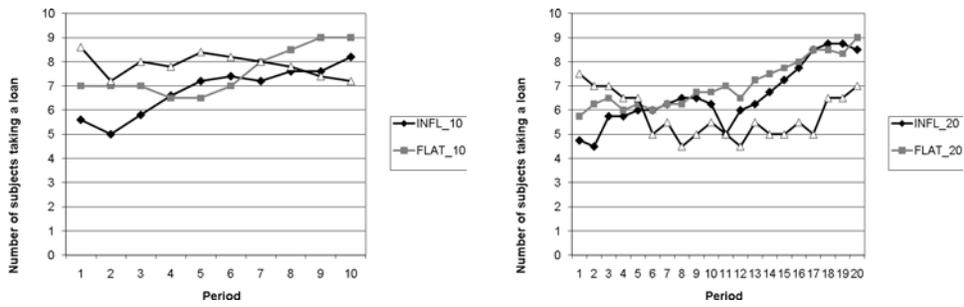
Figure 6: Time series of allocative efficiency in the ten treatments with certain and uncertain time horizon compared to simulations with minimally intelligent (MI) agents
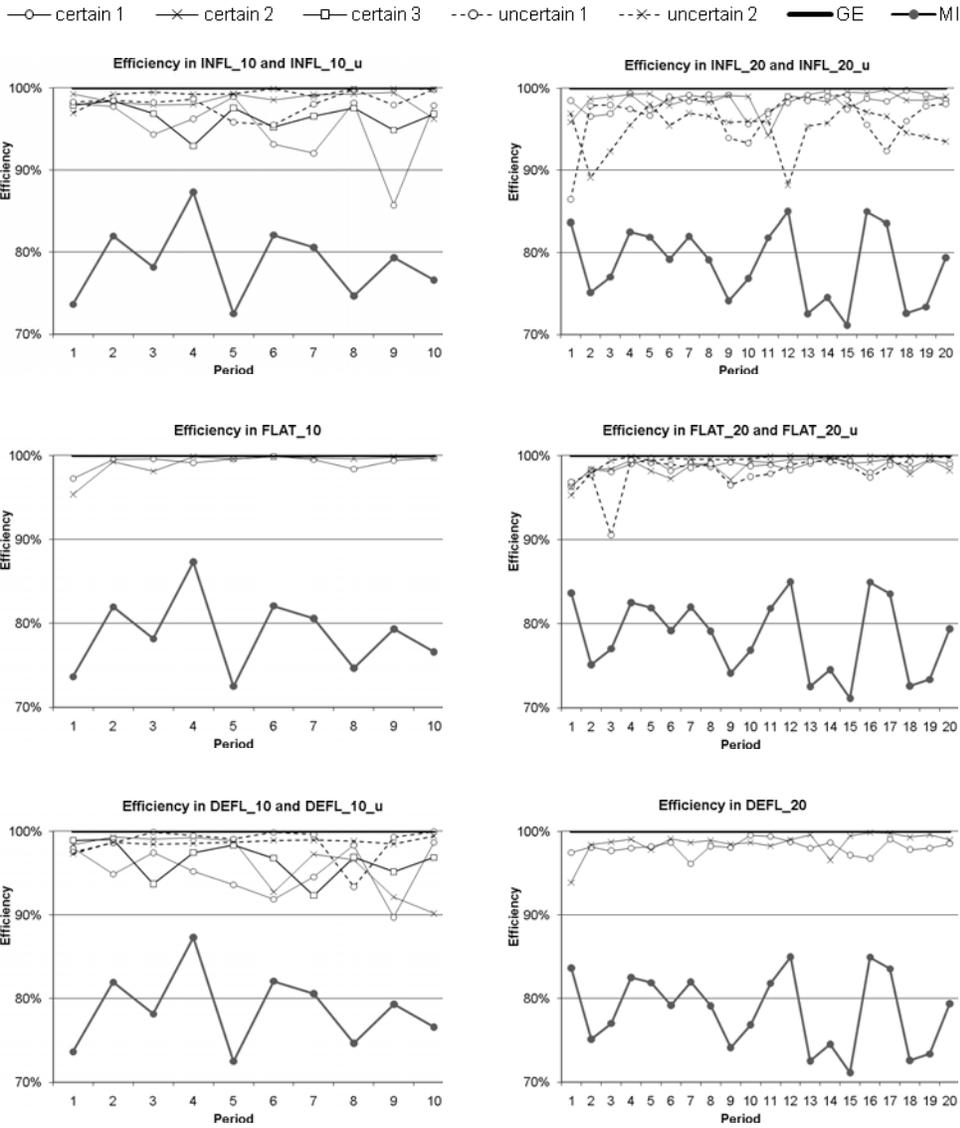
Figure 7: Results for control treatment FLAT_20_rho_15%
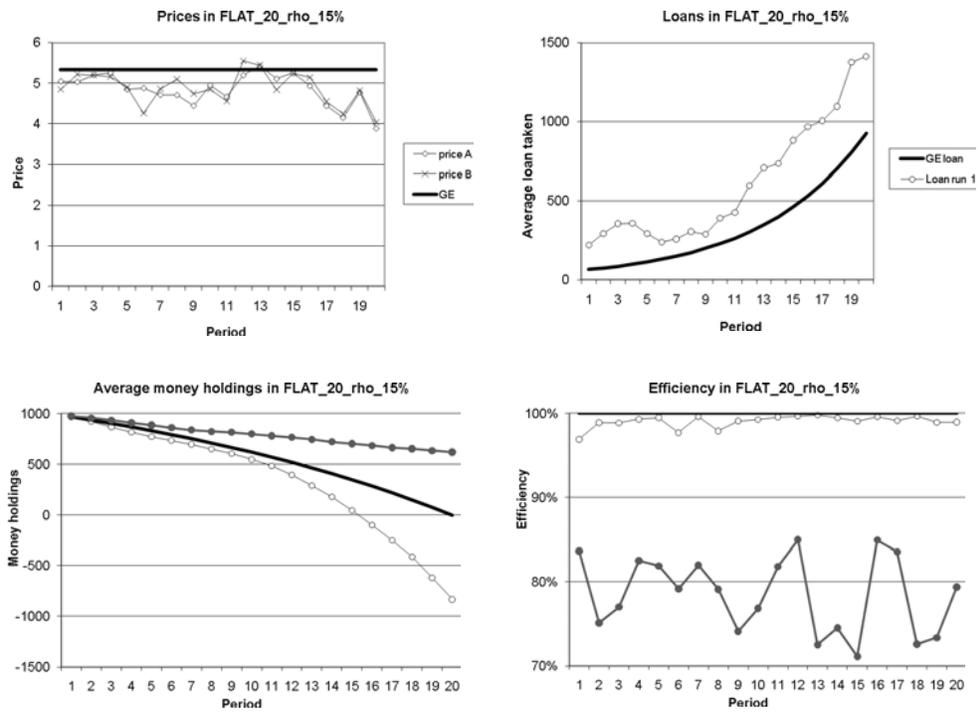
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General

This is an experiment in market decision making. If you follow the instructions carefully and make good decisions, you will earn more money, which will be paid to you at the end of the run.

This run consists of 8 to 12 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 you will get 1,000 units of money at the start of the experiment. Depending on how many units of goods A and B you buy and on the proceeds from selling your goods and borrowing from a bank, this amount will change from period to period.

During each period we shall conduct a market in which the price per unit of A and B will be determined. All units of A and B will be sold at this price, and you can buy units of A and B at this price. 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 you are willing to pay to buy good A, and the amount you are willing to pay to buy good B (see the center of Screen 1). The sum of these two amounts cannot exceed your current holdings of money at the beginning of the period plus the amount you borrow from the bank. The interest rate for money borrowed is 5 percent per period. The computer will calculate the sum of the amounts offered by all participants for good A. (= Sum_A). It will also calculate the total number of units of A available for sale (n_A, which will be 1,000 if we have five participants each with ownership claim for 200 units of good A). The computer then calculates the price of A, $P_A = Sum_A/n_A$.

If you offered to pay b_A to buy good A, you will get b_A/P_A units of good A.

The same procedure is carried out for good B.

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

Points earned$_t$ = 10 * (b$_A$/P$_A$ * b$_B$/P$_B$)$^{0.5}$ * beta^{t-1}

In this session, beta =1 which means that the last term beta^{t-1} is always equal to 1.

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

*10 * (100 * 100)$^{0.5}$ = 1,000 points.*

Your money at the end of a period (=starting money for the next period) will be :

your money at the start of the period

plus the amount you borrow

plus money from the sale of your initial entitlement to proceeds from A or B

minus the amount you pay to buy A and B

minus interest on your loan

minus repayment of the money borrowed

If you end a period with negative money holdings, you have to take a loan of at least this amount to proceed (roll the loan over). Your final money holdings will be relevant to your score only after the close of the last period. If you have any money left over it is worthless to you. If your money is not enough to pay back any loan then your remaining debt will be divided by 4 and this number will be subtracted from your total points earned. Screen 2 shows an example of calculations for Period 2. There are 10 participants in the market, and half of them have 200 units of A, the other half 200 units of B. Here we see a subject entitled to proceeds from 200 units of good B.

Information on bids and transactions in good A	Information on bids and transactions in good B	Earnings calculation	Cumulative earnings so far. This number/1000 will be the US-$ you get

Period

	2			Remaining time [sec]:	12

				Money at start of period	1280
Total amount offered for A	6700	Total amount offered for B	6229	Money borrowed	200
Price of A	6.7	Price of B	6.2	Proceeds from selling A and B	1246
				- Payment for buying A and B	1350
				- interest payment	10
Units of A sold for you	0	Units of B sold for you	200	Final money holdings	1366
Proceeds from sales of A	0	Proceeds from sales of B	1246	- Repayment of money borrowed	-200
				Start money next period	1166
Units of A you bought and consumed	104	Units of B you bought and consumed	104		
Payment for buying A	700	Payment for buying B	650	**Your earnings this period:**	**1044**
				=10*squareroot (A*B)	

period	price A	consumption of A	price B	consumption of B	Money	earnings	cumulative earnings
1	6.5	62	5.9	85	1280	722	722
2	6.7	104	6.2	104	1166	1044	1766

The earnings of each period (shown in the last column in the lower part of Screen 2) will be added up at the end of run. At the end they will be converted into real Dollars at the rate of 400 points = 1 US-$ and this amount will be paid out to you.

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How to calculate the points you earn:

The points earned are calculated are calculates with the following formula:

$$\text{Points earned} = 10 * (b_A/P_A * b_B/P_B)^{0.5}$$

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 more goods mean more points, however, to get more goods you usually have to pay more, thereby reducing your money balance, which will limit your ability to buy in later periods.

		Units of good B you buy and consume									
Units		**0**	**25**	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**
of A	**0**	0	0	0	0	0	0	0	0	0	0	0
you	**25**	0	250	354	433	500	559	612	661	707	750	791
buy	**50**	0	354	500	612	707	791	866	935	1000	1061	1118
and	**75**	0	433	612	750	866	968	1061	1146	1225	1299	1369
con-	**100**	0	500	707	866	1000	1118	1225	1323	1414	1500	1581
sume	**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 and both prices are 20, then your points from consuming the goods are 612. Your net change in money is 200 (A or B) * 20 = 4,000 minus 50 * 20 minus 75 * 20 = 1,500, so you have 1,500 more to spend or save in the next period.

2) If you buy 150 units of good A and 125 units of good B and both prices are 20, then your points from consuming the goods are 1,369. Your net cash balance is 200 (A or B) * 20 = 4,000 minus 150 * 20 minus 125 * 20 = -1,500, so you have 1,500 less to spend or save in the next period.

Questions

<u>General Questions.</u>

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

<u>Questions on how the market works</u>

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 you initial cash endowment?
8. Can you take a loan?
9. How high is the interest rate for a loan?
10. What is the maximum amount you can offer to buy units of good A?
11. What is the maximum amount you can offer to buy units of good B?
12. What is the maximum amount you can offer to buy A and B combined?
13. What happens to the units of A or B in your initial endowment?

<u>Profits and Earnings</u>

14. If the total offers for good A are 16,000 and 1,000 units are for sale, what is the resulting price per unit of A?

15. If the total offers for good B are 18,000 and 1,000 units are for sale, what is the resulting price per unit of B?

16. If you offered 2,000 to buy good A and the price is 20, how many units do you buy?

17. If you offered 4,000 to buy good B and the price is 20, how many units do you buy?

18. You offered 3,000 to buy A and 2,000 to buy B. The prices are 10 for A and 20 for B respectively.

     i)   How much do you earn from selling your 200 units of A?

     ii)   How many units of A do you buy?

     iii)   How many units of B do you buy?

     iv)   What is your net cash position?

19. If you end a period with negative 850 units of money and you want to spend 500 on each of A and B the next period. What is the minimal loan you have to take?

20. How many points do you earn if you have 2,000 units of money left in the last period?

21. How many points are deducted if you have negative 2,000 units of money in the last period?