SUFFICIENCY OF AN OUTSIDE BANK AND A DEFAULT PENALTY TO SUPPORT THE VALUE OF FIAT MONEY: EXPERIMENTAL EVIDENCE

By

Jürgen Huber, Martin Shubik, and Shyam Sunder

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YALE UNIVERSITY
Box 208281
New Haven, Connecticut 06520-8281

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

Sufficiency of an Outside Bank and a Default Penalty to Support the Value of Fiat Money: Experimental Evidence[#]

Jürgen Huber,[a, §] Martin Shubik,[b] and Shyam Sunder[b]

[a] University of Innsbruck, Austria

[b] Yale University, USA

Abstract

We present a model in which an outside bank and a default penalty support the value of fiat money, and experimental evidence that the theoretical predictions about the behavior of such economies, based on the Fisher-condition, 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 and use of the bank rate to influence inflation or deflation, although other institutions could provide alternatives.

JEL-classification: C73, C91

Keywords: Experimental gaming, Bank, Fiat money, Outside bank, General equilibrium

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[§] Corresponding author. Innsbruck School of Management, University of Innsbruck, Universitaetsstrasse 15, A-6020 Innsbruck, Austria. Tel: 0043 512 507 7554, Fax: 0043 512 507 2846.

E-mail addresses: juergen.huber@uibk.ac.at (J. Huber), martin.shubik@yale.edu (M. Shubik), shyam.sunder@yale.edu (S. Sunder).

1. INTRODUCTION

In this paper, we test in laboratory 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. Laboratory evidence supports the proposition.

In a finite economy, opportunity to borrow combined with competition enables individuals to utilize any fiat money they possess to pay back debt; in essence a loan is a backwards operator in time. It enables one to buy now and pay later with currency that is accepted by the bank but would be of no further value to the agent at the end of the game. (see Shubik, 1980 and Dubey and Geanakoplos, 1992).

Jevons (1875), Hahn (1965, 1971), Shubik and Wilson (1977), Bewley (1986), and Kovenock and de Vries (2002) among others in an extensive literature, have offered various reasons for the value of fiat or symbolic money. Most of these studies provide sufficient but not necessary conditions that include: (1) money is assumed to be wanted by most if not all to address the failure of the double coincidence of wants at low cost; (2) money provides a convenient way to trade and reduce transactions costs; (3) it carries default penalties (for not repaying debts); (4) its value is supported by high enough dynamic expectations[1]; (5) its issue is controlled by an outside bank that can enforce its use up to a point (Knapp 1905); and (6) it serves as insurance against economic fluctuations (see Bewley (1986), Karatzas et al. (1984)).[2] Conditions (3) and (5) are addressed in this paper.

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

[2] 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

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 for financing transactions. While a bank is not necessary, we already know that it is sufficient to achieve this result.[3]

We investigate the behavior of a minimal economy that includes an outside bank and a default penalty on unpaid loans.[4] We 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. The other reasons to support the existence of fiat money merit separate investigation outside the scope of the present 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 and examine in laboratory.

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some form of disutility or loss related to the money value of the loss. For (4), see Grandmont's (1983) analysis of the role of expectations in supporting the value of money.

[3] Complexity of a modern monetary economy resides in its institutions and laws. Since they have evolved with society, assuming the existence of an outside bank is at least as reasonable as assuming exchanges based on pairwise search. The former better captures the economies we live in, while the latter is better suited to studies in early economic anthropology. They address different questions.

[4] Minimal mechanisms abstract away the details to retain only the basic features necessary to be playable in the laboratory; see Huber et al. (2010).

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.[5] 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 with certainty Dubey and Geanakoplos (1992) prove that the individuals can maximize their payoff by ending the game with zero money balance. When termination is uncertain, some money will be held to retain purchasing power if the economy continues as is shown by Bewley (1986). We investigate experimentally these theoretical predictions, and find that the observed data are well-organized by the predictions of the model depending on the length of the game, the natural discount rate β for intertemporal consumption, and the bank rate of interest ρ.

Section 2 presents the theoretical structure and Section 3 the laboratory implementation of the economy. Section 4 compares the theoretical predictions of the competitive general equilibrium with data observed in laboratory economies populated by profit motivated human agents and minimally intelligent (MI) algorithmic traders (specified later in detail) simulated on a computer. Conclusions of the paper are summarized in Section 5.

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5 "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. We note, but cannot deal with in detail here, that the presence of uncertainty modifies the Fisher Equation (see Karatzas et al., 2006)."

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2. THE THEORY

Monetary economics deals with dynamics, and institutions are society's way of implementing the process. Multiple alternative mechanisms can serve a given financial function. An outside agency, or central bank, is a simple mechanism to actively or passively control the supply of money. Furthermore, as in history and life, there are no natural initial or terminal points to the economic process. Since experimentation in laboratory requires that initial and terminal conditions be specified, care in modeling and simplification is necessary 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 passive device to provide a flexible fiat money supply by making loans at a fixed rate of interest.[6]

Neither the source and distribution of the initial supply of fiat money, nor the disposal of this supply at the end, is addressed in a typical economic model. Implementing the economy as a finite playable game forces one to account for both the source and the disposal explicitly. The initial money holdings are "outside money" without an obligation to repay. At the end of the finite game, 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. In practice, however,

[6] 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.

individual indebtedness to the government is achieved more through taxation than through loans.

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 final period. The market is structured as a clearinghouse. The backward induction predicted by rational expectations was not observed in the data. Duffy and Ochs (1999) utilize a search-theoretic model based on the work of Kiyotaki and Wright (1989) to study which of several commodities emerges as money. We take as given the existence of two markets and a rudimentary central bank. The model is kept simple in order to provide conditions conducive to formation of rational expectations.

Consider an economy with two types of traders, who can trade two goods for money. One type of trader has an endowment of $(a, 0, m)$[7] 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 give 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 the bank fix in advance the quantity of money to be lent, or the interest rate to be charged, or fix both as its modus operandi? Since we have chosen the bank to be a strategic dummy, the interest

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

rate is a fixed parameter in the game, and the bank always has sufficient funds to lend (thereby we avoid having to discuss the details of the meaning of bank reserves). The bank permitting the loans to be rolled over 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 positive money balances carried from one period to the next do not earn any interest.[8] A more general game would permit traders to deposit in as well as borrow from a bank, thereby earning returns on any surplus financial capital. In the model economy, we limit the players to borrowing, keeping 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 game requires the individuals to make two types of decisions: a financial decision to borrow an amount d and a market decision to bid money payments b_i with $i = 1, 2$ for each of the two goods. We structure the market as a "sell-all" game where all individual endowments of goods are automatically put up for sale.[9] For T periods of the game we set the utility function of the traders as

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

[9] Of three minimal market mechanisms - sell-all, buy-sell, and double auction - in full feedback general equilibrium settings, we use the first and the simplest in minimizing the number of decision variables. 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.

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

where β is a natural time discount rate for consumption, $10\sqrt{x_{it} y_{it}}$ 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:

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

and

$$p_1 = \frac{2b_1}{a} = \frac{(1+\rho)(1-\beta)}{2\rho(1-\beta^T)a} m \tag{3}$$

with the inter-period linkages given by:

$$\begin{aligned} b_t &= (1+\rho)^{t-1} \beta^{t-1} b_1 \\ p_t &= (1+\rho)^{t-1} \beta^{t-1} p_1 \end{aligned} \tag{4}$$

and finally,

$$d_t = \frac{(1+\rho)^{t+1}}{\rho} \frac{1-\beta^t}{1-\beta^T} m - \frac{(1+\rho)^t}{\rho} \frac{1-\beta^{t-1}}{1-\beta^T} m - (1+\rho)^t m \,. \tag{5}$$

This is changed in both models when there is the opportunity to borrow. In the buy-sell model, individuals make an additional decision q about the amount of their endowed good they offer for sale. See Quint and Shubik (2008) for the mathematical derivations of the properties of the sell-all and buy-sell games, and Huber et al. (2010) for their empirical properties in laboratory environments.

Each laboratory session has T time periods, and ends with 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).

The expressions given above are simplified to the following when $1+\rho = 1/\beta$:

$$b_t = b_1,\ p_t = p_1, \text{ and } d_t = \beta^{T-t}m/(1- \beta^T). \tag{6}$$

In the experiment, it is specified that at the termination of play after settlement of debt, any positive money balances held by the traders are of no value and any unpaid debts are of negative salvage value (subtracted from the payout to the respective players). Zero worth of positive money balance at the end of the final 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. The presence of the bankruptcy penalty of sufficient size serves to rule out strategic bankruptcy where the gains from borrowing and defaulting could otherwise outweigh the losses from the punishment for default.

In actual economies, payments of money and delivery of goods come with varying lags. 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. Subjects have to submit money bids for the purchase of the two goods. This so-called "cash-in-advance" condition is implicit in any simultaneous move model of price formation.

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 by the equations above, together with the amounts borrowed and bid.[10]

Use of a payoff function, which is multiplicative and symmetric in the consumption of two goods, makes sure that there is a strong incentive to consume equal amounts of both goods. Since the money becomes worthless after the final period, ending with money on hand is not an equilibrium solution when opportunity to borrow is available. 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 the 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 in which no money is held by the traders at the end as all income is consumed in paying off the debt. Thus the finite horizon economy must be "cash consuming" for any positive rate of interest.[11]

[10] Many variants and extensions of this model 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. Further results with exogenous uncertainty, i.e., uncertain assets under low and high information conditions have been considered by Bennie (2006).

[11] In an infinite horizon economy with interest rate $1+\rho = 1/\beta$, 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.

3. DESIGN OF THE EXPERIMENT

To study the influence of several variables on market outcomes like price level, price path, and efficiency we 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 (β=1), flat (β=1/1.05) or decreasing (β=1/1.15). We keep the interest rate (ρ) fixed at 0.05 throughout except in one session for robustness check, in which it is 0.15.

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

(4) *Repetition of session with the same subjects.* In several treatments we let subjects play a second and sometimes third round of the same game to examine if repetition of playing against the same subjects affects the outcomes of the economy.[12]

We conducted 11 different treatments with a total of 25 experimental runs (see Table 1).

(Insert Table 1 about here)

[12] 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 were paid privately in cash after playing the first run of a treatment, before the second (and sometimes a third) run was conducted with the same procedure. INFL_20 and FLAT_20, had two runs while INFL_10 and DEFL_10 had three with the same cohort of subjects.

Parameters fixed across all treatments were: a = 200, m = 1,000, and ρ = 0.05. Five treatments had T = 10, while the other six had T = 20 to explore the effect of varying the number of periods. With ρ = 0.05 fixed, the natural discount rate β was varied to achieve the theoretically predicted equilibrium price paths to be inflationary (β = 1), flat (β = 1/1.05) or deflationary (β = 1/1.15). We label the 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.[13]

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 Table 1 for details).

We conducted checks for robustness by repeating sessions with the same subjects, with a different interest rate, and a different default penalty (100 percent instead of 25 percent of negative money holdings). Since outcomes of laboratory economies can be sensitive to subject experience, we did the second and third runs of INFL_10 and DEFL_10 with the same cohort of students as the corresponding first runs. Also the second runs of INFL_20 and FLAT_20 were conducted with the same subjects as the

[13] 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 (supposed to last 20 periods but stopped earlier because of a computer problem).

corresponding first runs.[14] To check the robustness of our results we conducted one additional run with a higher interest rate of 15 percent. Specifically, a = 200, β = 1/1.15, ρ = 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%. Finally, we conducted two runs of INFL_20 with a default penalty of 100% (instead of 25%) of negative money holdings. Results for these treatments are presented in Section 4.7.

3.1. Implementation of the Experiment

In all treatments, subjects were seated at networked computer terminals, with view of their screens isolated by means of sliding walls. Direct communication among subjects was not permitted. Written instructions (see Appendix A) were given to each subject, read out loud and any questions were answered privately. A questionnaire was used to verify that subjects had understood the instructions. The experiment was conducted and subjects' earnings were paid to them in cash privately.

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 at market determined price. Each subject had the same starting endowment of money m = 1,000 at the

[14] Three 10-period runs could be conducted in a single session, but only two 20-period runs were possible in a single session because of time constraint.

beginning of period 1. The interest rate for loans (ρ) was fixed at 5 percent per period in all treatments.[15]

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 and loan balances (positive and negative) are carried over to the following period.

The trading mechanism is a simple sell-all 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 (unlimited amount of) loan he takes out from the bank. To derive the price for *A* the computer divided the sum of all money bids for *A* by the total number of good *A* in the market (5 times 200 = 1,000). 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 the interest on any loan. Money holdings influence earnings directly only in the very last period of the session when either 25 or 100 percent of any negative money holdings is deducted from the total points earned. Positive money holdings at the end of the session have no value and are discarded.

[15] Except for one robustness check (labeled FLAT_20_rho_15%) where the interest rate was set to 15 percent.

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 session. Specifically,

$$\text{Points earned} = 10 \cdot \sqrt{x_{ij} * y_{ij}} \cdot \beta^{Period-1} \qquad (7)$$

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.[16] 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 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 described above are also conducted with uncertainty of the time horizon (the subjects learned only that the experiment would run for either 8-12 periods or 15-25 periods).

Repetition 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 repeated once (for 20-

[16] Variations of the interest rate ρ could be used for the same purpose, but we use variations of β, except for one robustness check where ρ is set to 0.15.

period runs) or twice (for 10-period runs) with the same cohort of subjects in contiguous intervals of time.

In this exploratory study we opted for a relatively large number of different treatments, while keeping the number of runs per treatment low. All treatments were conducted with software written in z-Tree (Fischbacher 2007). Eight runs were conducted at Yale University and 17 at the University of Innsbruck.[17] Each run lasted for 60-90 minutes. Payments averaged $22 at Yale and €18 in Innsbruck. While most subjects had participated in other economics experiments earlier, no student participated in more than one of the treatments of the type presented in this paper. Four treatments were repeated with the same subjects to explore any effects of learning.

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 tends to get 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 as well as prices drops (see Tables 2 and 3).[19]

[17] We could not test for subject pool differences, as the eight runs conducted at Yale were those with undergraduate students and uncertain time horizon, while all 17 runs with certain time horizon were conducted in Innsbruck. All Innsbruck students were in the Master's program in Economics or Business and we do not expect any subject pool differences to affect the market level outcomes in these economies.

[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 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.

[19] 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

(Insert Table 2 about here)

(Insert Table 3 about here)

3.2. Economy Populated 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. The first is the competitive equilibrium derived from assumption of optimization by individual economic agents. The second is the outcome from markets populated by minimally intelligent agents who randomly pick their choices from a uniform distribution over their bounded opportunity sets (see Gode and Sunder, 1993 and Huber et al. 2010). The choice of minimal abilities required for operating in multiple markets for goods and credit, and the details of operationalizing the MI agents are given next.

Several considerations are relevant to implement MI agents in this economy. First, such agents need external constraints on the domain from which they can choose their actions. Second, since they do not anticipate the future, 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

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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 solutions given in Tables 2 and 3 as a benchmark for comparing the experimental results.

set available to them. Note that the behavior of an economy with these three features (no value for residual money balances, presence of a debt market, and populated with such myopic investors) should be expected to differ significantly from the behavior of an economy populated with intelligent agents. When opportunity to borrow is available, intelligent agents can anticipate the future including the possibility of default and its consequences (e.g., bankruptcy penalty). 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 MI agents.

We specify the MI 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 credit limit is set at the initial money holdings m=1,000. The max function ensures 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 MI 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 the 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 sessions 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. 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 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 simulations with the same three natural discount rates (0, 5 and 15 percent).

4. RESULTS

Although the rules of the game are simple, the terminal conditions, price and borrowing behavior call for a sophisticated strategy. We 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. We focus on the development of prices, loans, money holdings, and efficiency. In addition, the effects of an uncertain time horizon, experience, and an alternative interest rate are explored. In Section 4.8 we will also explore how efficiently the markets function when they are populated by MI agents as defined above.

4.1. 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 the GE price predictions). Figure 1 shows the realized and equilibrium price paths in ten treatments.[20]

(Insert Figure 1 about here)

In each run the slope of price paths conforms to the theoretical GE prediction, i.e., 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)

All the regression coefficients are 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 (t-tests). 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 -

[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).

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 three runs (all of the same subject cohort) 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 predictions appear to anchor the general tendency of price levels in these economies.

4.2. Borrowings

In all treatments, subjects could borrow without limit at an interest rate of 5 percent per period. With the initial endowment of money set 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 INFL- and FLAT-treatments, but decreasing in DEFL-treatments. This holds irrespective of the run length and uncertainty of horizon.

(Insert Figure 2 about here)

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 the 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 markets populated with profit-motivated human agents are largely consistent with the theoretical predictions (with the exception of three DEFL_10-runs).

4.3. 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 with average money holdings near zero, 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 large deviations, e.g., negative holdings in all runs of 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 unpaid 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 with positive money holdings take out higher loans to get rid of positive money holdings in later periods.

Our data reveal that money balances in these economies are affected by the length of the experiment as predicted by the GE. Table 5 gives average money holdings after period 10, separated for the 10-period and 20-period economies. 10^{th}-period holdings in the 20-period-treatments are on average 467, roughly half of the initial endowment, while they are on average -159 in the 10-period economies. 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.

(Insert Table 5 about here)

Money holdings can be a proxy for the individual ability to coordinate, anticipate and solve the complex backward induction problem they face. For unknown reasons, traders do not spend all their money. 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 did not spend only 3.3 percent of their total money balance, compared to 15.8 percent for the non-borrowers; the difference is present in all treatments.

(Insert Table 6 about here)

To understand money balances further, we 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). These averages are shown in Figure 4. Over the 10 or 20 periods of the runs, the average unspent money tends to decrease steadily towards a plateau which is lower for the borrowers than for non-borrowers.

(Insert Figure 4 about here)

Decreases in money balances may reflect learning effects as well as attempts to convert money into units of consumption near the end of the runs before it becomes worthless. We calculated period-wise numbers of subjects taking a loan separated for INFL, FLAT, and DEFL-treatments. The results, presented in Figure 5, show that 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 are taken in the INFL-treatments. By the end of the markets this relationship reverses, and more loans are taken in the FLAT- and INFL-treatments than in the DEFL-treatments. This holds for 10- and 20-period markets and conforms to theoretical predictions (see Table 3).

We also counted the numbers of subjects who never or always took a loan. Of 250 possible cases we found only 16 (6.4 percent) never took a loan, but 80 (32.0 percent) borrowed every period. These extremes occurred more frequently in the 10-period markets, where consistency is easier than in the 20-period markets. Specifically, the two percentages were 11.7 and 45.8 in the 10-period runs, and were markedly lower at 1.5 and 19.2 in the 20-period runs.

(Insert Figure 5 about here)

4.4. Efficiency

Efficiency of these economies is measured by the total points earned by subjects as a percentage of the maximum possible.[21] The markets populated by MI agents had the efficiency of 78.6 percent on average, presumably a consequence of the economy's structure. Recall that we use a sell-all market, and a multiplicative earnings function which is relatively insensitive to changes in holdings around the peak, i.e., holding equal amounts of the two goods. This earnings function tends to yield high efficiency even when 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.

[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.

In the laboratory experiments efficiency ranged from 71.1 to 100 percent for individual periods, and averaged from 95.2 to 99.2 percent for individual runs. 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 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 drives 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] The fact that non-borrowers earn much less than borrowers is not surprising in the experimental setup chosen, as taking loans is rational and earnings-increasing. Each subject starts with 1,000 units of cash that are worthless in the end, so this money should be used up to pay interest on loans. If 10 periods are played and the interest rate is 5%, an average loan of 2,000 per period (thus paying 100 units of interest per period) is better than no-loan strategy but not yet optimal (because of

[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. Final money holdings are not considered in this analysis.

discounting). A subject who confines himself to using the 1,000 he is endowed with has only one third of the buying power (and earnings) of his peer who borrows 2,000. This difference increases further as the borrowers use 96.7 percent of their money on average (see Table 6), while the non-borrowers use an average of only 84.2 percent, thus lowering the buying power of the latter.

The difference in earnings is especially large in the INFL-treatments (23.7 percent on average across all treatments). The non-borrowers in INFL_10 underperform even the MI agents. In FLAT the difference is smaller (10.7 percent) and almost disappears in DEFL (0.5 percentage points). We do not have an explanation for these differences. We conclude that borrowers spent almost all of their money, bought more goods than non-borrowers, and earned 11.6 percent more on average.

(Insert Table 7 about here)

4.5. Length of time horizon: 10- vs. 20-period-economies

In each treatment, subjects were endowed with 1,000 units of money. As this money mostly was (and should have been) used up to pay interest, loans (and therefore prices) in shorter horizon treatments are predicted by theory to be higher than in the corresponding periods of the longer horizon 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 10^{th} 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 columns 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 in line with the theoretical predictions. The theoretical predictions of price paths and levels hold for the deflationary treatments as well; 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)**.**

As discussed earlier, the length of the horizon also affected the money balances. At the end of the 10^{th} 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.

4.6. Uncertainty of Time Horizon

The theoretical GE benchmark has been derived only for economies with certainty of horizon. To check the robustness of the model in predicting the outcomes of these economies, we conducted runs in which subjects did not know the length of the horizon for sure. With the length of the horizon certain, it is theoretically possible, albeit with implausible assumptions, 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, in all other respects except that they only knew the number of periods would be between 8 to 12 (for economies that actually lasted for 10 periods) and between 15 to 25 (for economies that actually lasted for 20 periods).

The complexity introduced by this uncertainty may induce lower spending by risk-averse subjects to avoid the possibility of ending up with negative money balances in case the economy runs for long. Final money holdings of treatments with and without uncertainty of horizons are compared in Table 8.

(Insert Table 8 about here)

We see that in three of the four cases (INFL_10, INFL_20, and DEFL_10) money holdings are higher for the uncertain than for the certain horizons. Only in FLAT_20 do we see the opposite to be true (with a difference of roughly 220 which is smaller than any of the other three differences). Over all, the average money holdings at the end are -122 in the four treatments with certain horizons and 392 in the treatments with uncertain horizons. Thus, subjects seemed to be more careful, and thriftier, in presence of uncertainty about the time horizon. A logical consequence of the higher money holdings is that lower borrowings lowered prices under uncertainty. Consequences for efficiency (98.0 percent under certainty and 97.5 percent under uncertainty) are small.

4.7. Robustness Checks: Repetition and Interest Rate

Although we found evidence of learning over periods within individual runs (which is common in most laboratory experiments), the learning process seems to have plateaued 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 of these economies were highly efficient from the start, repetition of runs with the same subjects led to improvements roughly as often as to deteriorations (as measured by proximity of borrowing and price levels to the GE predictions).

In the replication of FLAT_20 with a higher interest rate (FLAT_20_rho_15% in Figure 7), the data are as close to the theoretical GE predictions as they are in other FLAT treatments.

(Insert Figure 7 about here)

Additional runs with higher bankruptcy penalty (μ equal to 100% of negative money holdings instead of 25% in the runs discussed so far) for INFL_20 economy were conducted as a robustness check. The results with the quadrupled penalty are qualitatively unchanged (see Figure 8). The higher default penalty does makes agents more cautious in borrowing to avoid negative money balance at the end of the session, yielding lower prices and higher final money holdings. However, the overall efficiency shows little effect.

(Insert Figure 8 about here)

4.8. 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, ignore the natural rate of discount (β) 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 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 to occur in the MI economies (as charted in the respective columns 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 of 1,000 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; outcomes of experiments with human subjects are much closer to the GE predictions.[23,24]

Tables 6 and 7 of money left unspent and the earnings with and without loans respectively, no numbers are given for MI. Recall that the MI agents are designed to spend all their cash each period and each agent takes a loan each period within the permitted constraints. The same is true for Figures 4 and 5.

We conclude that economies populated by minimally intelligent agents, as interpreted here, still reach 75-80 percent efficiency. This is significantly lower than the

[23] 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.

[24] We repeated the MI simulations by imposing a credit limit of zero (instead of 1,000). Without interest-driven (5 percent per-period) cash depletion in the economy, prices remain near 5.0 on average (instead of declining progressively from an average of 7.38 in period 1 to 5.02 in period 20). Efficiency of the MI economies remains around an average of 80 percent irrespective of the credit limit imposed on the MI agents.

efficiency of human economies because, being insensitive to the influence of β, MI-agents do not produce the distinct price paths that GE theory predicts and experiments with humans produce.

5. CONCLUSIONS

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 general equilibrium 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. 2010), managing a borrowing relationship with a bank is more complex and requires additional faculties such as some elementary way to predict future states.

Commodity as well as fiat money can provide transaction services. However, unlike commodity money, fiat money has no alternative uses. Once it is without a transactions function, as it is in period T+1 of an experimental game, it has no salvage value whatsoever in contrast with barley, tea or cacao (all of which have been used as a means of exchange). We could have used chocolate bars in our experiments and theory and experiment tell us that there would be a consumption motivation to leave some over after the markets close. We note that fiat money can be supported institutionally in many ways. In two earlier experiments we provide evidence for workability of two different arrangements - expectations (Huber et al. 2010) and an efficient clearinghouse (Angerer et al. 2010). This paper presents evidence on the efficacy of a third arrangement—an outside bank. We find that markets populated by profit-motivated human subjects and an outside bank work well and are able to interpret different natural discount rates and produce price paths that reflect general equilibrium predictions.

This study presents a large number of different treatments, as we consider it an exploratory study that should open new paths of research. Some possible future paths are: (i) fixing total credit supply and auctioning this fixed amount of credit, instead of fixing the interest rate; (ii) the bank being a strategic player (profit-seeking human subject) instead of being a dummy, (i.e., the bank decides actively and individually about who gets the credit at what rate, making credit supply and interest rate flexible; (iii) using a utility function which is not so insensitive at the peak; (iv) letting positive money balances earn a positive interest rate (instead of zero); and (v) combining a credit limit with a lenient enough bankruptcy penalty that renders strategic default theoretically desirable under some circumstances.

Appendix: Instructions for INFL_10

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.

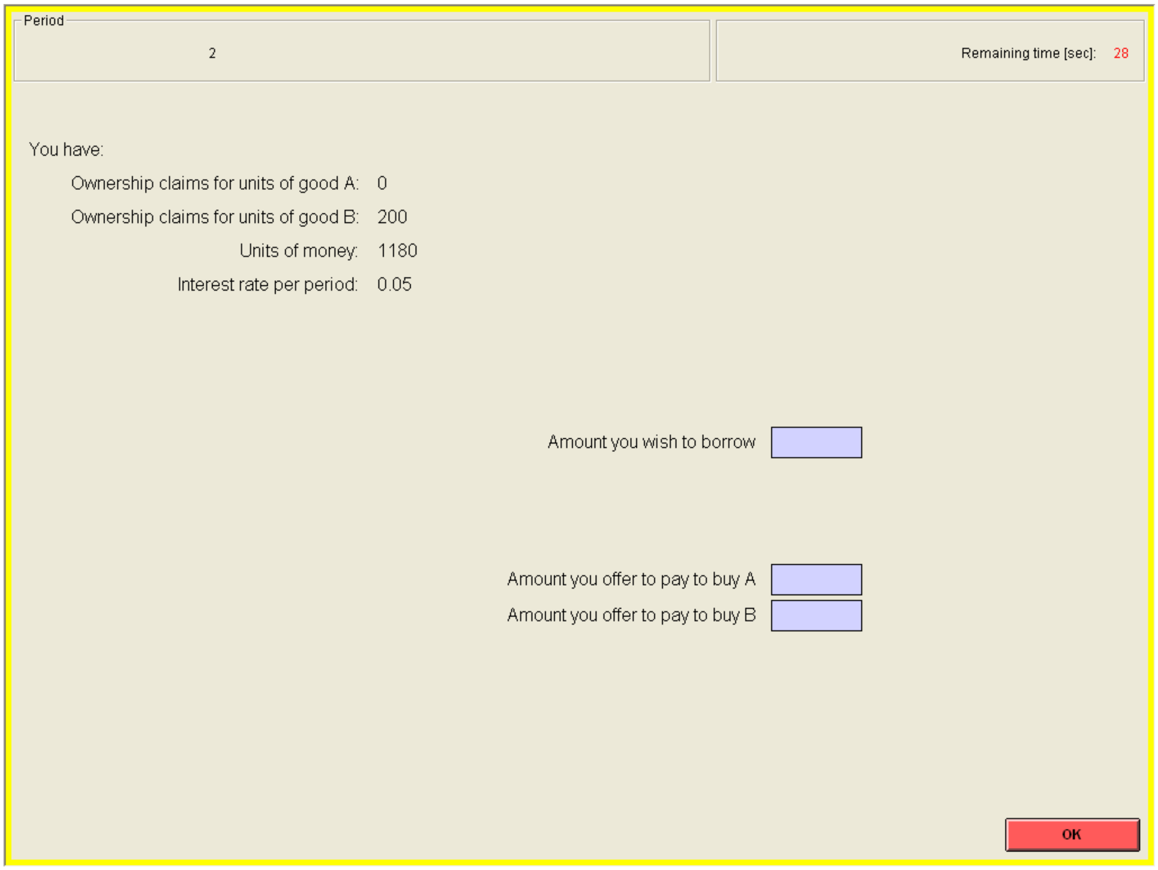
This run consists of 8 to 12 periods and has 10 participants. At the beginning of **each** period, five of the participants will receive as income the proceeds from selling 200 units of good A, for which they have ownership claim. The other five are entitled to the proceeds from selling 200 units of 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:

$$\text{Points earned}_t = 10 * (b_A/P_A * b_B/P_B)^{0.5} * \beta^{t-1}$$

In this session, β =1 which means that the last term β^{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

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

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

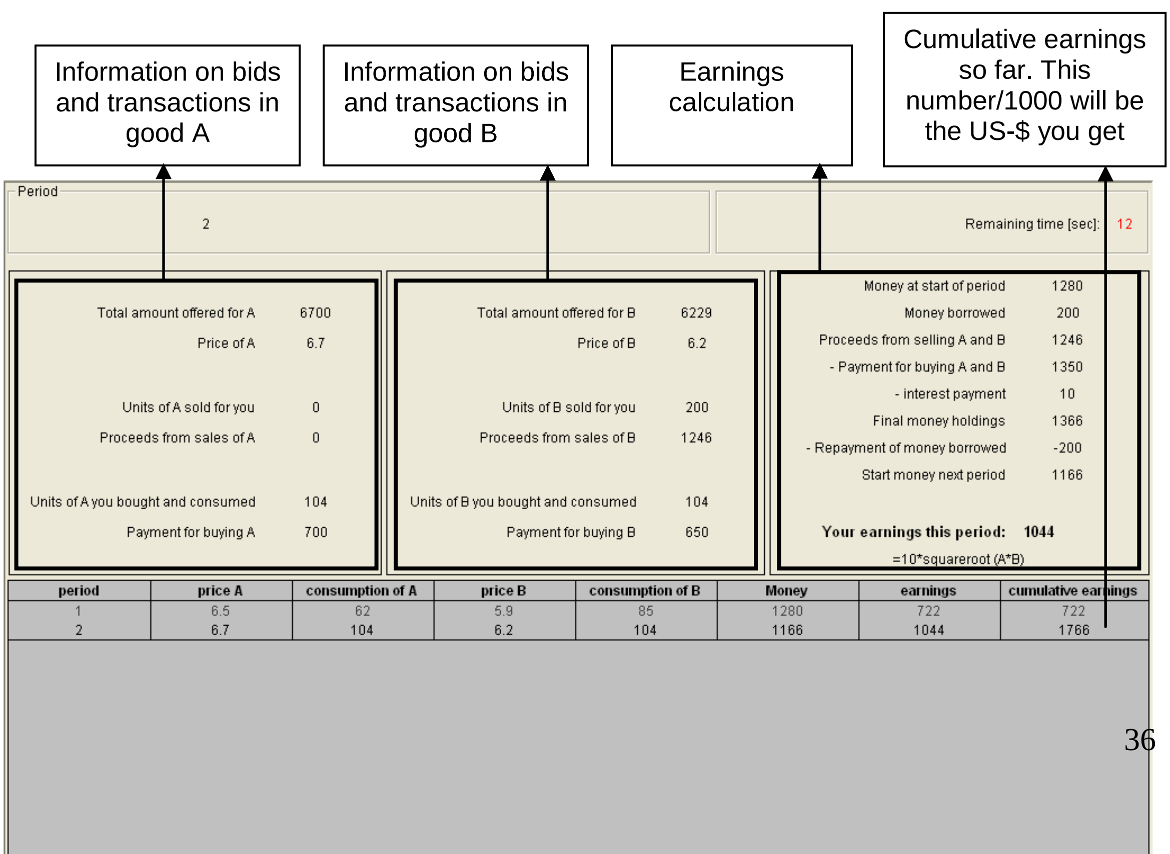
plus money from the sale of your initial entitlement of A or B

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.



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.

How to calculate the points you earn:

The points earned are calculated 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 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 and both prices are 20, then your points from consuming the goods are 612. Your net change in money is 200

(of good A or B) x 20 - 50 x 20 - 75 x 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 (of good A or B) x 20 - 150 x 20 - 125 x 20 = -1,500, so you have 1,500 less to spend or save in the next period.

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 real dollars?

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 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?

Profits and Earnings

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 in 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?

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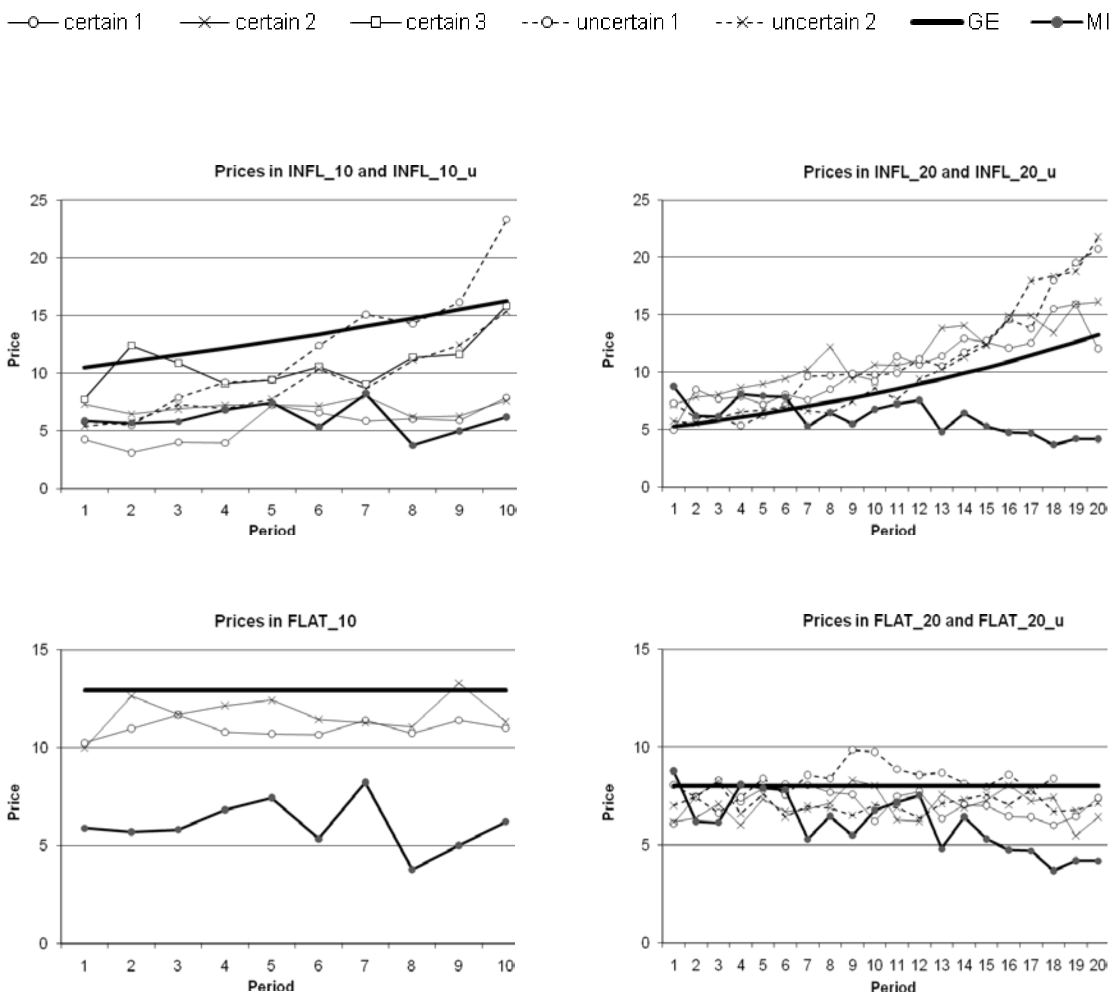
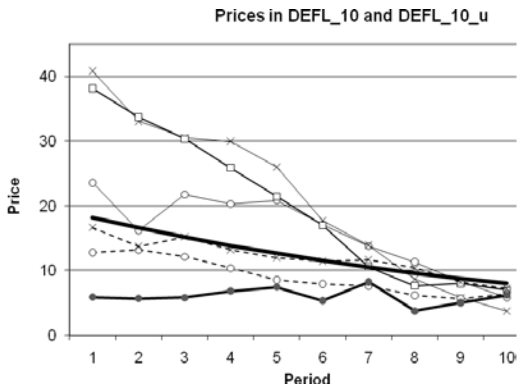
Figure Legends

Figure 1: Time series of prices (averages of goods A and B for each run) in the ten treatments with certain and uncertain time horizons compared to simulations with minimally intelligent (MI) agents and GE predictions




Prices in DEFL_10 and DEFL_10_u
Price
Period
0
10
20
30
40
1
2
3
4
5
6
7
8
9
10

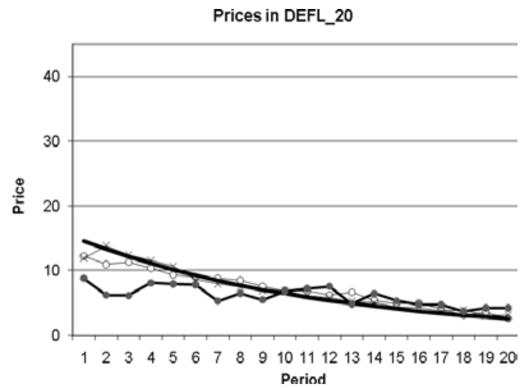

Prices in DEFL_20
Price
Period
0
10
20
30
40
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Figure 2: Time series of borrowings (average loans taken) in the ten treatments with certain and uncertain time horizons compared to simulations with minimally intelligent (MI) agents and GE predictions

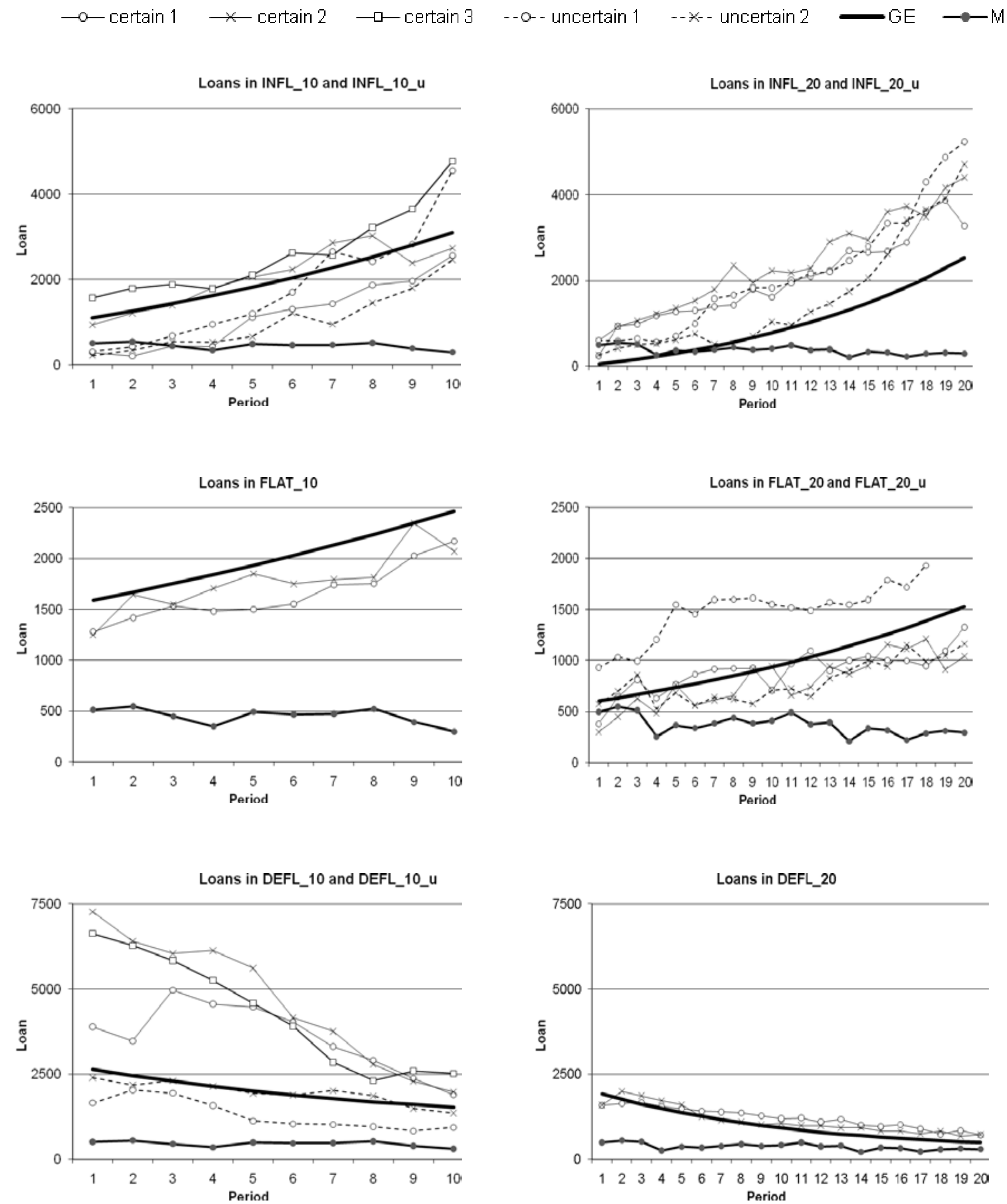


Figure 3: Time series of average money balances at the end of each period in the ten treatments with certain and uncertain time horizons compared to simulations with minimally intelligent (MI) agents and GE predictions

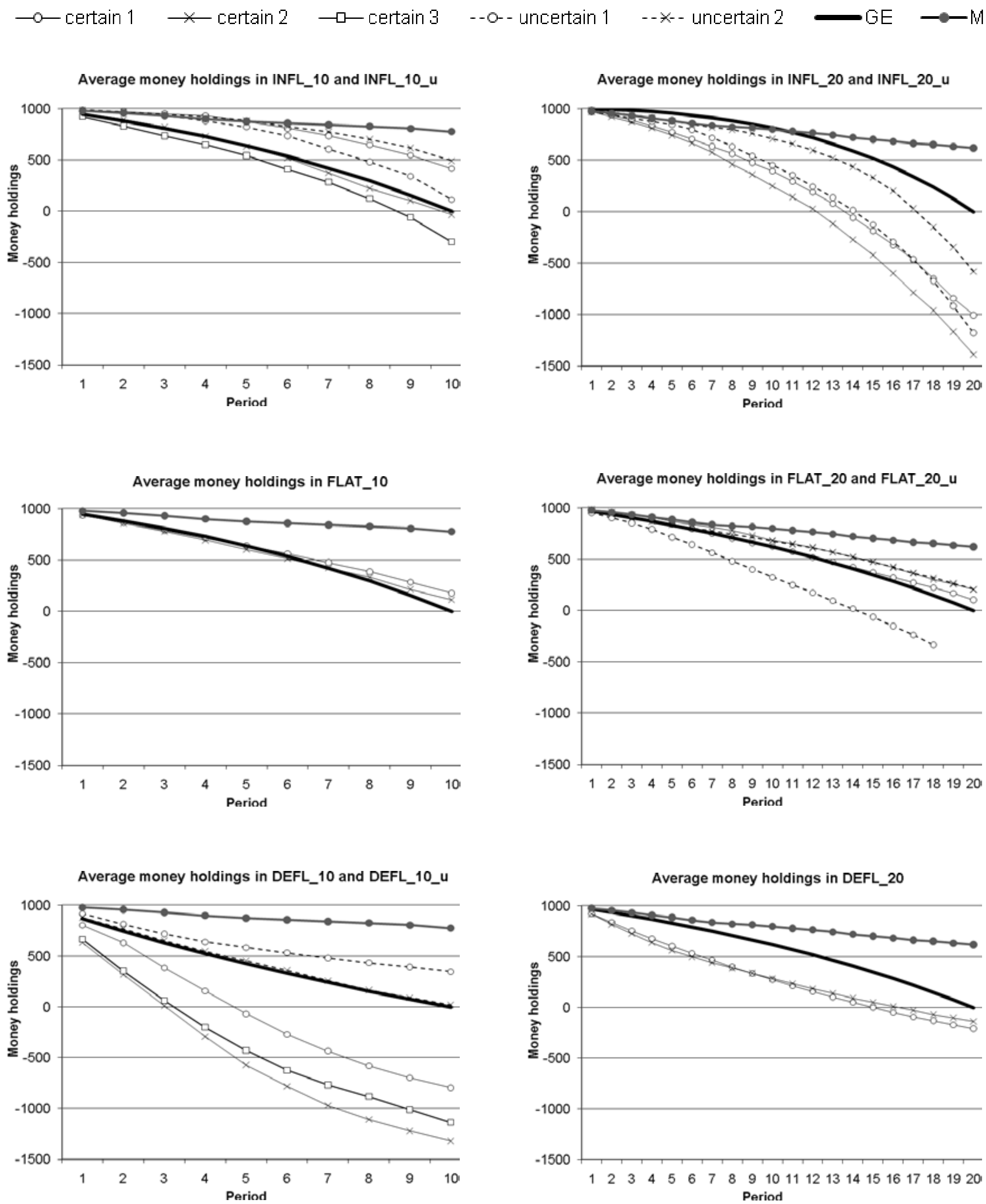
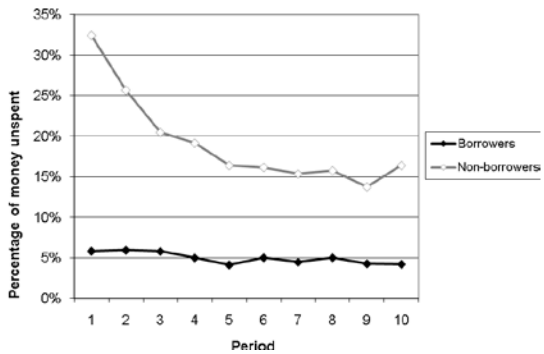


Figure 4: Average percentage of money kept unspent by borrowers vs. non-borrowers in the 10-period treatments (left) and the 20-period treatments (right)



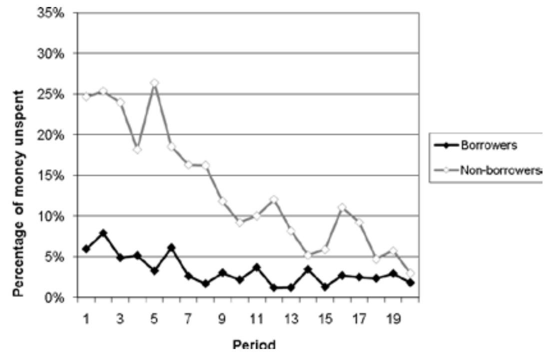
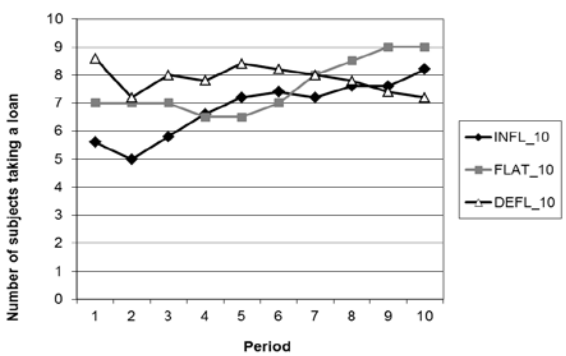


Figure 5: Average number of subjects (out of 10) taking a loan in the 10-period treatments (left) and the 20-period treatments (right)



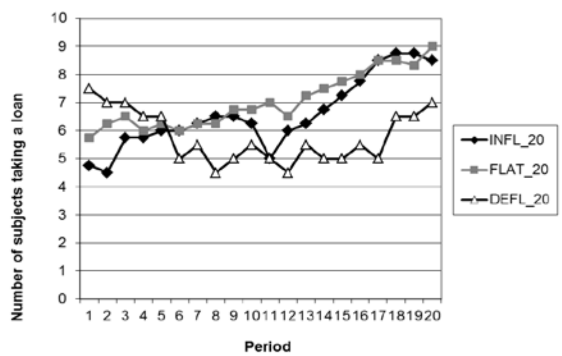


Figure 6: Time series of allocative efficiency in the ten treatments with certain and uncertain time horizons compared to simulations with minimally intelligent (MI) agents and GE predictions.

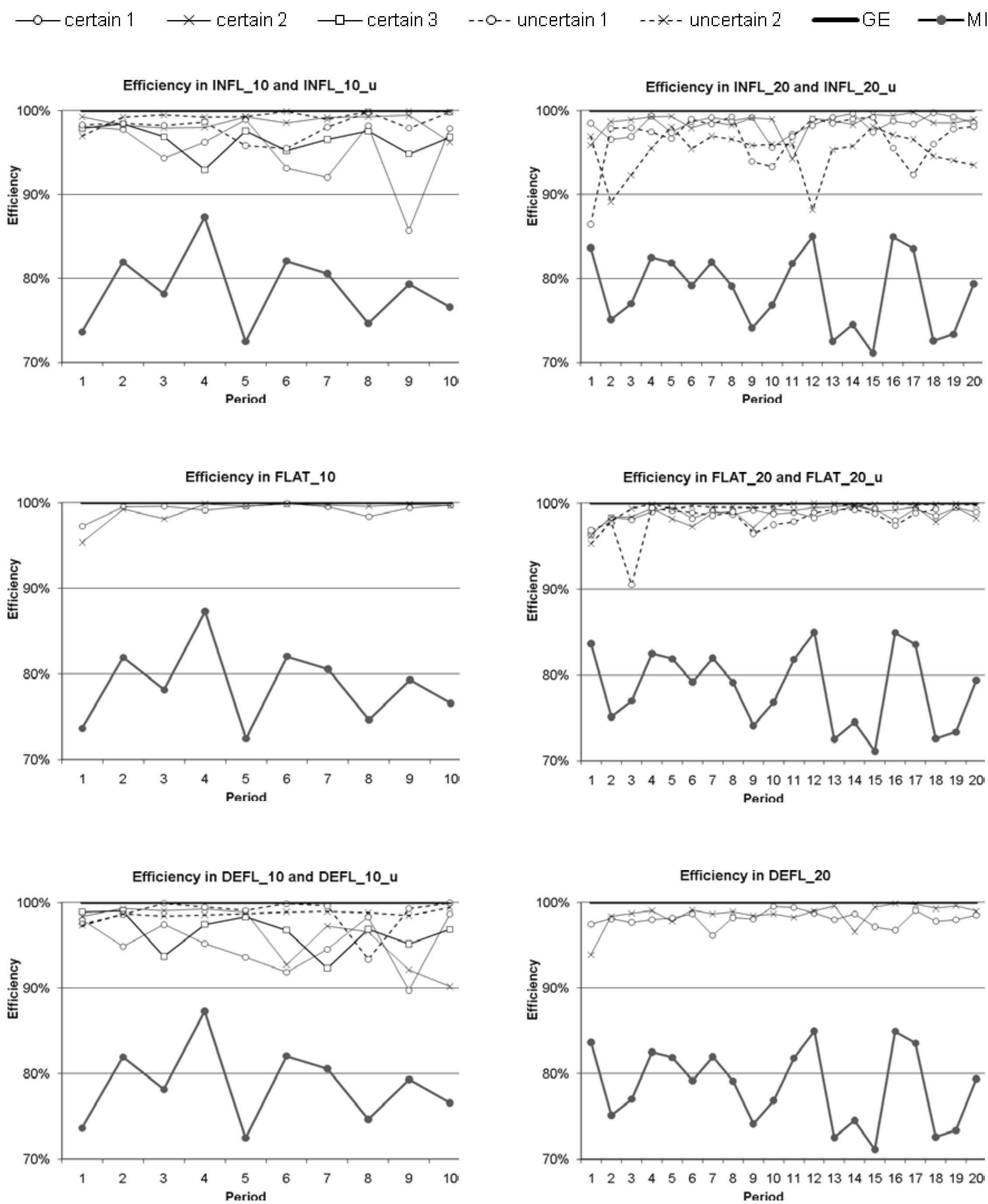


Figure 7: Results for control treatment FLAT_20_rho_15%

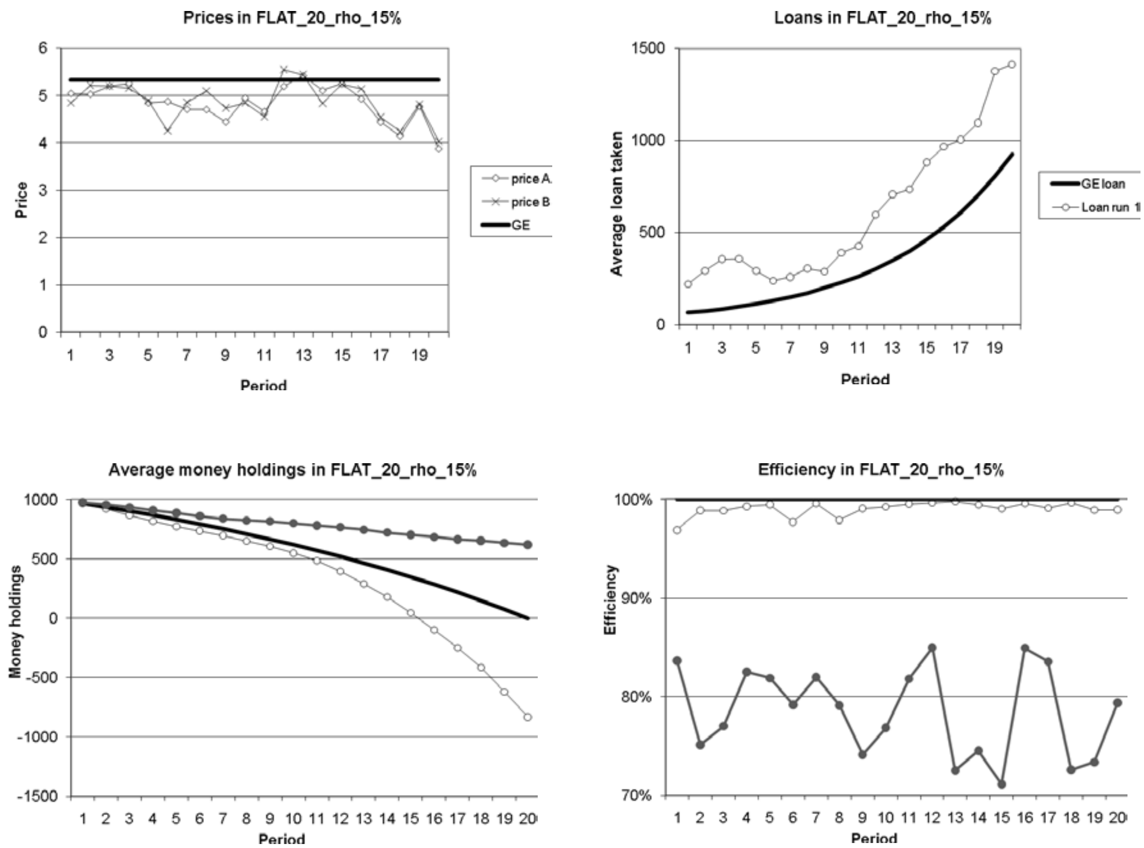


Figure 8: Comparison of results for INFL_20 with penalty

of 25% and 100% on negative money holdings

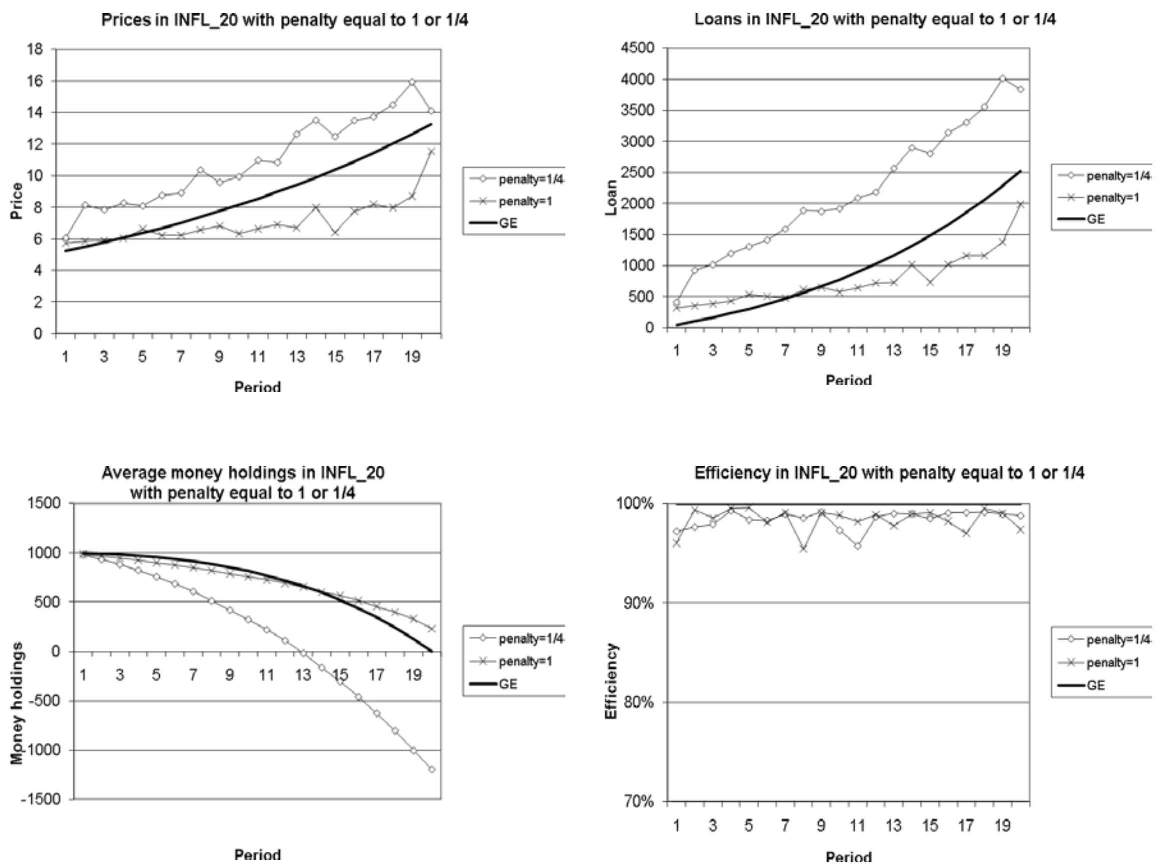


Table 1: The experimental design*

(Interest rate ρ = 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, ρ = 0.15**
Periods	10	20	10	20	10	20	20
Natural discount rate	β=1	β=1	β=1/1.05	β=1/1.05	β=1/1.15	β=1/1.15	β=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 Horizon	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 Points earned by 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 (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**			