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An Experimental Comparison of Two Exchange Mechanisms
An Asset Market versus a Credit Market

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The Lucas (1978) asset pricing model lies at the heart of modern macro-finance. At its core, it provides an analysis of the equilibrium price of a long-lived financial asset in an economy where consumption is the objective, and the sole purpose of the asset is to smooth consumption through time. Experimental tests of the model are mainly confined to Crockett *et al* (forthcoming 2019) and Asparouhova *et al* (2016), both of them using a particular instantiation of the Lucas Model. Here we adopt a different instantiation, extending their analyses from a two-period oscillating world to a three-period cyclical world. We also go one step further, and compare this asset market solution (to a consumption-smoothing problem) with the perhaps intuitively more reasonable solution provided by a credit market, in which agents can directly trade consumption between periods. We find that the latter is more efficient in smoothing consumption, and that prices in the credit market are closer to their equilibrium values than those in the asset market, and also less volatile. We find evidence of uncompetitive trading in both markets.

Keywords: Asset Market Experiment; Bewley Incomplete Markets; Consumption Smoothing; Credit Market; Exchange Economy; General Equilibrium; Herfindahl Index; Intertemporal Choice; Lucas Tree Model; Re-trade Ratio.
JEL Codes: C90, D50, E51, G12.

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1. Introduction

The motivation of this paper is to study and compare the performance of two markets (an asset market and a credit market, in which agents can directly trade consumption through time) with respect to two intertwined key items of interest: (1) whether the market manages to reach its equilibrium price; (2) whether agents manage to smooth their consumption through time.

We start with an experimental test of a particular instantiation of the Lucas (1978) asset pricing model. In its simplest form this model considers an infinite discrete-period world in which there is perishable money and a long-lived asset which pays a dividend in money. Income, in the form of money, varies from period to period, and utility is derived from end-of-period money holdings. With a concave utility function, it is desirable for end-of-period money holdings to be smoothed through time. This can only be achieved by individuals trading the asset in an asset market; so the role of the asset market is solely to facilitate end-of-period money holdings smoothing.

Key previous experimental papers are those of Crockett *et al* (forthcoming 2019) and Asparouhova *et al* (2016). In some ways their instantiations are similar to ours, but there are also marked differences. Crucial to their stories, and indeed that of Lucas, is that income in the form of money varies from period to period. Crockett *et al* achieve this directly, by having exogenous income which oscillates deterministically. They have two kinds of agents: in odd periods one type has a high income and the other a low income; in even periods it is the opposite. However, the dividend from the asset is constant. In contrast, Asparouhova *et al* (2016) make the dividend from the asset vary stochastically – either high or low – occurring with given probabilities, independently of time and past history. We follow the route of Crockett *et al* (forthcoming 2019), but extend their model to have *three* types of agents, with their incomes varying cyclically and deterministically; this extension allows us to explore the robustness of the model to increasing heterogeneity. Asparouhova *et al* (2016) go in a different direction, incorporating not only money and an asset, but also including a bond which pays a fixed known rate of interest.

The Lucas model is set in an infinite horizon world with constant discounting. At the beginning of the problem each agent is given a one-off endowment of the asset. In each period each agent gets an endowment of (perishable) money. In order to implement this in the laboratory, we adopted the usual experimenter's method: of replacing an infinite horizon world with constant discounting by a random horizon world with a constant continuation probability; this latter being the equivalent of the constant discount factor. This meant that any particular repetition (which we called a 'sequence') of the Lucas model would last a random number of periods. We told subjects that there would be a random number of sequences. At the beginning of each sequence the endowments of the asset were reset to their initial values, and everything was started afresh, giving us several repetitions of tests of the Lucas model.

We add to the previous literature by comparing this asset market solution (to a consumption-smoothing problem) with an alternative solution provided by what we call[1] a 'credit market'. In this, agents can directly trade consumption in one period for consumption in another.

This paper starts with a literature review. We then outline the Lucas model, interpreting it from the perspective of our experiment, and we derive the key propositions, particularly about the equilibrium asset price and consumption-smoothing, that we test with our experiment. We then derive the corresponding theory for a credit market. We then discuss our experimental design, before reporting the key findings in the experiment. Finally we conclude, exploring the implications of our findings.

2. Literature Review

There is a vast experimental literature from the 80's on asset pricing which has enhanced our understanding of price formation in asset markets. Early studies like Plot and Sunder. (1982), Forsythe *et al* (1982), Friedman *et al* (1984), motivated agents to trade by providing heterogeneous dividend values. They found that the market price tends to converge towards the rational expectation value. Smith *et al* (1988) introduced a design in which all investors receive the same dividend from a known probability distribution at the end of the T trading periods; they found that this design tended to generate price bubbles. In general, researchers have shown that the phenomenon of asset price bubble is robust to a variety of changes in the market structure (see Van Boening *et al* (1993), Porter and Smith (1995), Caginalp *et al* (1998), Lei *et al* (2001), Dufwenberg *et al* (2005), Haruvy and Noussair (2006), Haruvy *et al* (2007), Hussam *et al* (2008), and Kirchler *et al* (2012)). In these studies a market was created for a dividend-paying asset with a lifetime of a finite number of periods with the asset structure being common knowledge. Another stream of literature studied the static capital asset pricing model in the laboratory with only asset-derived income and no labour/endowment income; the main studies here are Bossaerts and Plot (2002), Asparouhova *et al* (2003) and Bossaerts *et al* (2007).

Another relevant strand of experimental literature conerns consumption smoothing. Earlier experimental work on consumption smoothing includes Hey and Dardanoni (1988), Carbone and Hey (2004), Noussair and Matheny (2000), Lei and Noussair (2002), and Ballinger *et al* (2003). The received

[1] We considered alternative terminologies: forward market, futures market, cash-in-advance market, and finally settled on this.

literature considered consumption smoothing as an individual choice problem in the familiar life cycle consumption model (for example, Hey 1980). Differently from the market approach presented here, individuals smooth their income stream over~~between~~ a fixed number of periods through saving at fixed interest rate. The general finding of this literature is that subjects smooth consumption but do so inefficiently (see Duffy 2016 for a survey).

In our experimental design we follow and extend the design of Crockett *et al* (forthcoming 2019) for testing the Lucas model with heterogeneous agents and time-varying private income streams. In each session of Crockett *et al,* 12 subjects exchanged assets against cash in an indefinite horizon world. The indefinite horizon was implemented by a roll of a six-sided die, implying a stopping probability of 1/6. In this exchange economy, individuals have a motive to trade the asset in order to smooth consumption between periods. Crockett *et al* had subjects trading an asset in the market which paid a certain dividend (2 cash units in one, 3 in another treatment) at the beginning of each period to asset holders. After each period one subject rolled the die and a '6' would terminate the session. Crockett *et al* reported strong evidence for consumption smoothing, and found that prices were close to equilibrium in their main treatment. In comparison to the asset market of Crockett *et al*, we examine a more complex setting by increasing the level of induced agent heterogeneity: in our design we have *three* different types of agents with cyclical incomes whereas Crockett *et al* had *two* different types with alternating high and low incomes.

Asparouhova *et al* (2016) also investigate the Lucas tree model in an indefinite horizon world, but there are a couple of important differences in their design to ours and also to the one of Crocket *et al*. First, Asparouhova *et al* had subjects trade *two* securities for cash; a fixed-income consol that pays 0.5 cash units in each period and a risky asset which pays 0 (bad state) or 1 cash unit (good state) according to the state of the economy. Half of the subjects are endowed with units of the consol; the other half are endowed with units of the risky asset. Their cash endowments alternated over periods. Our asset corresponds rather to the consol than the risky asset in Asparouhova *et al* as the stopping probability is the only exogenous risk in our setting. In the design of Asparouhova *et al*, subjects simultaneously price two long-lived securities in the market. The risky asset in their design and its transition probabilities from good to bad states implies complications for subjects' expectations and forecasts of equilibrium prices (in this context, Asparouhova *et al* refer to 'residual price forecasting risk'). Such forecasting risk is absent in our setting. Second, in that paper, subjects consume the cash they hold at the end of the final period only. Thus, Asparouhova *et al* induce preference for consumption smoothing through the stopping probability rather than through the choice of the payoff function as we do. The purpose of the study of Asparouhova *et al* is to look at risk avoidance *via* diversification and market reaction. Their results provide support for their qualitative pricing and consumption predictions; prices move with fundamentals and agents smooth consumption. At the same time, nevertheless, the data sharply differs from the quantitative predictions as asset prices display excess volatility to the point that the equity premium is negative in good times, and subjects do not hedge price risks. Asparouhova *et al* conclude that the deviations of the data from the model arise through the disagreement of subjects' expectations with respect to the underlying perfect foresight model.

Crocket *et al* (forthcoming 2019) and also Asparouhova *et al* (2016) suggest that the consumption smoothing motive can imply a tendency of asset prices to reflect fundamentals. Halim *et al* (2016) directly tested this hypothesis in an indefinite horizon setting (with stopping probability 1/6), where subjects exchanged a risky asset that paid 0 (bad state) or 1 cash unit (good state) for cash in the market. In their design, some subjects had a constant endowment in each period and thus no induced trading motive; consumption smoothing would require no trade. Other subjects had different endowments in odd and even periods and thus consumption smoothing required trade. Halim *et al* report that market prices are higher in the presence of subjects with no induced trading motive than when subjects must trade for consumption smoothing. Interestingly, Halim *et al* report overpricing of assets compared to the risk-neutral fundamental value in all their treatments.

In line with Crocket *et al* (2017), Asparouhova *et al* (2016) and Halim *et al* (2016), our participants are motivated to engage in trade in order to offset income fluctuations they face over time, therefore the main reason for trading should be consumption smoothing. In sharp contrast to these studies, we also study a credit-market where short-lived securities are transacted. Thus, we are able to compare consumption smoothing and price discovery in markets with long-lived versus short-lived securities. This is one of our key contributions[2].

Besides the Lucas tree model, the Bewley model is another important heterogeneous-agent dynamic general equilibrium exchange economy model (see the survey by Heathcote *et al* 2009)[3]. In this model, the consumer's labour income is subject to a shock. A riskless short-term asset facilitates individual consumption smoothing between periods. By employing a simple version of the Bewley model (which leads to identical consumption smoothing in equilibrium as the Lucas tree model in our design) we are able to compare consumption smoothing and price discovery in markets with long-lived versus short-

[2] Earlier contributions like Forsythe *et al* (1982) and Friedman *et al* (1984), and more recent contributions like Noussair and Tucker (2006), show that the future market is more efficient than the spot market, and that if there is a future market available the spot market converges to the equilibrium price more efficiently. However, these experiments do not have a consumption smoothing dimension.

[3] Bewley (1983) proves monetary equilibrium existence. Following Ljungqvist and Sargent (2004) we adopt the term Bewley model, whereas Heathcote *et al* refer to the standard incomplete markets model. In the equilibrium with many agents, households are able consume or trade units of the endowment. Trade occurs in exchange for a promise of R units of consumption next period, that is, a one-period credit contract.

lived securities. We are not aware of any other study that investigates a test of this model in the laboratory.

The question of the pricing of short-lived and long-lived assets is related to the effects of re-tradeability on asset prices. Three papers have investigated the re-tradeability effect in experimental markets. Lei, *et al* (2001), Dickhaut *et al* (2012) and Gjerstad *et al* (2015) compared market efficiency when assets had to be consumed immediately upon purchase with a situation in which assets could be resold after purchase until the end of the period. These studies find no differences in (mis-)pricing between these two conditions. Dickhaut *et al* (2012) and Gjerstad *et al* (2015) report higher efficiency when the asset is not re-tradeable. Gjerstad *et al* (2015) find that market efficiency of re-tradeable assets increases with the experience of traders. In contrast to our study, these studies investigate only short-lived assets which do not carry over from one period to the next. In our markets short-lived claims and long-lived assets can be re-traded within a period. Efficiency seems not to increase with experience in the (long-lived) asset market.

3. Background Theory

We confine our discussion to one repetition of the Lucas model; this is equivalent to one sequence in our experiment – all sequences were identical in structure. The scenario is as follows. There are a number of individuals in society. There is perishable money, and a durable asset, and there is a market in the asset. There is a fixed aggregate amount of the asset, with the initial endowments differing from individual to individual. Each unit of the asset earns a fixed and known money dividend d each period. Individuals receive, each period, an exogenously-determined quantity of money m_t, with this differing from individual to individual. During each period individuals can trade money for the asset. The money holding of individuals at the end of each period is converted into utility, and aggregated over the lifetime to determine average utility. Utility in period t is given by $u(c_t)$ where $u(.)$ is the (concave) conversion scale into money and where c_t (end-of-period money) is given by

$$c_t = m_t + da_t - p_t(a_{t+1}-a_t)$$

where a_t is the asset holding at the beginning of period t and p_t is the price of the asset in period t. The optimising decision for any individual in period T is to maximise

$$\sum_{t=T}^{\infty} \beta^{t-1} u(c_t) \tag{1}$$

subject to the expression above. Here β is the individual's discount factor.

The first-order condition for the optimal decision in period t is

$$u'(c_t)p_t = \beta u'(c_{t+1})(p_{t+1}+d)$$

In equilibrium, since the conversion scale is concave, the individual wants to smooth consumption, so we have that $u'(c_t)=u'(c_{t+1})$, and hence we get $p_t = E_t\beta(p_{t+1}+d)$.

In a stationary equilibrium $p_t=p_{t+1}=p$ and hence

$$p = \frac{\beta}{1-\beta}d \tag{2}$$

This is the equilibrium asset price. It has the obvious interpretation as being the discounted dividend income from holding one unit of the asset.

We now consider the credit market. In this, agents trade tokens in one period for tokens in another at some price. Let us assume a constant credit market price p. If an individual wants to buy s_t in money in period t, promising to pay it back in period $t+1$, then, at the price p, he or she will have to pay back ps_t in money in $t+1$. The first order condition for the choice of s_t in period t is

$$u'(c_t) = E_t\beta u'(c_{t+1})p$$

where $c_t=m_t-s_t$ and $c_{t+1}=m_{t+1}+ps_t$

Noting that m_t and m_{t+1} are exogenous, the optimality condition is $u'(c_t) = \beta pu'(c_{t+1})$. Once again assuming consumption smoothing this reduces to

$$p = \frac{1}{\beta} \tag{3}$$

This is the equilibrium credit price. It has the obvious interpretation: in equilibrium, one unit of money in period t is exchanged for p units in period $t+1$. Hence, in equilibrium, the discounted value of one unit of money in $t+1$ is equal to the value of one unit of money in t.

4. The Experimental implementation

There were 12 subjects in each experimental session. Sessions involved *either* the asset market *or* the credit market; no subject participated in both. The session started with one of the experimenters reading aloud over the tannoy system the Instructions for the experiment[4], and the subjects simultaneously reading written Instructions in front of them. Subjects were then asked if they had any questions on the *structure* of the experiment, and any questions were answered. Afterwards, each subject individually watched a video[5] describing the trading mechanism. Subjects were then asked if

[4] They can be found on the website devoted to this experiment.
[5] Again available on the website.

they had any questions on the trading mechanism in the experiment, and any questions were answered. They were then given a practice period of trading, which continued as long as they wanted. This did not count towards payment.

The Instructions stated that the experiment would consist of a random number of sequences each divided into a random number of periods. In each period, which lasted three minutes, trading of the asset, or trading in the credit market, could be carried out, using the familiar double-auction mechanism implemented using Z-tree[6]. As already noted, we employed a random stopping mechanism. At the end of every period of trading, one of the subjects publicly rolled a six-sided die: if it showed a number less than "6", the sequence would continue; if it showed a "6" that particular sequence would stop. In that case, if less than one hour had elapsed since the start of the first sequence a new sequence would be started[7].

In each period of the experiment, subjects were endowed with an income denominated it *tokens*. In our experiment, as we have already noted, there were three types of subjects, four of each Type, with their token incomes varying cyclically. Type I subjects had token incomes of 109, 53, 67, 109, 53, 67, and so on; Type 2 subjects had token incomes of 49, 113, 45, 49, 113, 45, and so on; Type 3 subjects had token incomes of 59, 51, 105, 59, 51, 105, and so on. All agents knew what their token incomes would be at the beginning of each period of the experiment. They also knew their endowments of the asset at the beginning of each sequence (these were 0, 5 and 5 for Types 1, 2 and 3 respectively). Payment for each and every period depended on how many tokens they had at the end of the period. We had two treatments which differed in terms of the conversion scale from end-of-period tokens to money. These are illustrated in Figure 1. We call them respectively the 'step payment function' and the 'concave payment function'. With both functions, if a subject ended a period with 79 tokens (the equilibrium end-of-period token balance) they would receive a payment of £1 for that period.

In order to explain our choice of these we need to show the parameters used in the experiment and the implied equilibrium. In the experiment the dividend payment *d* was 2, and the continuation probability was 5/6. Hence the equilibrium price was 10 from equation (2) above. Table 1 shows the equilibrium. For example, Type 1, who starts off with no assets, should buy 3 units in period 1, sell 2 units in period 2, and sell 1 unit in period 3; thus getting back to zero holdings at the end of the cycle (period 4). It will be seen from the table that all three Types in all periods have an end-of-period token holding of 79. So they all smooth consumption and all have the same smoothed consumption. This explains our conversion scale in Treatment 1: effectively we were telling them that they should aim

[6] The program can be found on the site, as can the questionnaire administered at the end of the experiment.
[7] In the unlikely event that no "6" was thrown between one and two hours, we told the subjects that we would stop the experiment that day and continue it on another. In practice this never happened.

for end-of-period tokens holdings of at least 79; this guarantees them a payment of £1 each period. This, of course, does not *guarantee* consumption smoothing at 79 but it is a strong hint. In Treatment 2, we followed Crockett *et al* and had a smoothly concave conversion scale. Again, end-of-period tokens of 79 leads to a payment of £1, but there is nothing to guarantee that subjects will consumption-smooth. Notice that because of the concavity of the scale, end-of-period tokens holdings of less than 65 lead to losses; subjects were told that losses would be offset against profits. We did not allow them to trade in such a way that their tokens holding would fall below 45.

As far as the credit market is concerned, as once again we had a continuation probability of 5/6, the equilibrium price, given by equation (3) is 1.2. Once again we had token incomes varying cyclically and deterministically: Type I subjects had token incomes of 109, 53, 67, 109, 53, 67, and so on; Type 2 subjects had token incomes of 59, 123, 55, 59, 123, 55, and so on; Type 3 subjects had token incomes of 69, 61, 115, 69, 61, 115, and so on. The equilibrium is shown in Table 2. For example, Type 1 should sell 30 tokens in period 1, getting 36 tokens back if period 2 was reached, and, if it was, should then sell 10 tokens in period 2, getting back 12 if period 3 was reached. And so on.

5. Results

In total 192 subjects participated in the experiment: 12 subjects in each of four independent sessions for each of the four treatments. The subjects' average age was 22.23, the average CRT-score was 1.46,[8] and 47% were female subjects. By participating in the experiment subjects earned an average of £18.30. The experiment lasted on average 2 hours including the reading of the instructions and the private payment of cash to subjects. The various treatments are summarised in Table 3.

As we have made clear from the start, there are two key items of interest: (1) whether subjects managed to consumption-smooth; (2) whether the price reached its equilibrium. We note that (1) is not a necessary but is a sufficient condition for (2), assuming competitive like behaviour in the markets. This, however, depends on how the subjects behave.

[8] Subjects were asked to answer the three questions of the cognitive reflection test CRT (Frederick 2005) in the debriefings. The CRT-score measures the cognitive abilities of subjects. The individual CRT-score can take numbers between 0 and 3. Subjects with a higher CRT-score usually have a higher payoff in market experiments (e.g., Corgnet *et al* 2014, Breaban and Noussair 2015, Charness and Neugebauer forthcoming). The average CRT-score of our sample is comparable to 1.43 measured with Harvard University students as reported in Frederick (2005). The CRT questions were: (1) A hat and a suit cost $110. The suit costs $100 more than the hat. How much does the hat cost? (2) If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? (3) In a lake, there is a patch of lily pads. Every day the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of it?

Result 1 (Consumption smoothing). *Consumption smoothing is observed in each treatment. Consumption smoothing works better in the Credit Market than in the Asset Market, and better with the step payment function than with the concave payment function.*

Figures 2 show the mean payoffs in each period of each session of the experiment. Table 4 summarises the mean payoff by market and by payment function. The efficient consumption level in the experiment was 79 tokens which implied a payoff of £1 per period. The no-trade consumption level implied an average payoff of £0.333 with the step payment function and £0.2033 (Type 1), £0.1133 (Type 2) and £0.68 (Type 3) with the concave payment function.

1. The observed mean payoff level significantly exceeds the no-trade consumption level in each market and for each payment function.
2. The means recorded in Table 4 indicate that the Credit Market has higher consumption levels than the Asset Market for each payment function. The payoff differences between the Asset Market and Credit Market and the differences in the relative frequency of efficient consumption levels are significant at the 5 percent level for each payment function. The relative frequencies of efficient consumption are also significantly different between the Asset Market and Credit Market for both payment functions. In addition, the differences between the payment functions are significant for both markets. The results of the two-tailed two-sample t-tests are indicated in the bottom lines of Table 4.[9]

Result 2 (equilibrium pricing). *Close-to-equilibrium pricing is observed in both the asset and credit markets and with both the step and the concave payment functions. We find no differences between treatments on the relative absolute differences from equilibrium.*

Figures 3 and 4 show the mean payoffs, while Figures 4 and 5 show the mean price trajectories and the equilibrium price for each treatment condition. Table 5 records the mean prices and the mean of the absolute relative deviation from the equilibrium. This is a standard measure in the experimental asset market literature to identify mispricing (see Stöckl *et al* 2010). The relative absolute deviation is defined as follows.

$$\text{Relative Absolute Deviation} = \frac{\sum_{t=1}^{T} | p_t - Ep |}{TEp}$$

[9] The differences between the Step Asset Market and the Concave Credit Market treatments are not significant; the p-values are .966 and .732 respectively.

The mean prices are recorded in Table 5. In all treatment conditions, we observe no significant differences from equilibrium. In the Step Asset Market the deviation is economically large, because the price in one market (session SA4, see Figure 4) deviates more from the equilibrium than the others. The two-tailed one-sample t-test of the hypothesis of equilibrium pricing results insignificant at the 10 percent level; for the Step Asset Market treatment the p-value is .44. The recorded relative absolute deviation suggests no significant differences between treatments. The p-values are recorded in the table.

6. Mispricing

While on average, prices seem consistent with the equilibrium conditions, there are cases where departures are clear. These are particularly so in sessions SA4 and CA2, as can be seen from Figure 4. In session SA4 we see a clear bubble which continues on into the following sequence[10], while in session CA2 we see a clear bubble followed by a crash. Why might this be so?

There are three reasons that spring to mind. First, that 12 subjects were not enough to ensure competitive behaviour. Second, and related to the first point, that some subjects were deliberately re-trading in order to manipulate the market. Third, that subjects did not take into account the true continuation probability within each sequence.

Competitive equilibrium assumes a 'sufficiently large' number of participants. While many other, usually simpler, experiments have observed competitive behaviour with 12 or fewer subjects, perhaps this experiment is too complex and had too few subjects. It is possible that some subjects realised that the market was not truly competitive and hence that they could try and impose some monopolistic power. One obvious way to do this in the asset market sessions was to try and build up a large asset holding and then hold out for high prices when offering to sell. So, if the assets became concentrated in the hands of a small number of subjects, prices could be forced upwards. One measure of concentration (in the holding of assets) is the Herfindahl-Hirschman index[11], which we denote by *hhit*. One hypothesis therefore is that the price in the asset market may be an *increasing* function of *hhit*. Additionally, the Volume of Trade in the transaction may well have a negative effect on the price, if this monopolistic story carries any weight.

[10] The solid circles indicate the end of a sequence.

[11] Defined as $\sum_{i=1}^{I} a_i^2$ where a_i is the asset holding of subject *i (=1..12)*.

In the credit market, however, the opposite is true, since the objective is to smooth end-of-period token holdings. Here we would expect that price may be a *decreasing* function of *hhit*. However, the Volume of Trade may still have a negative effect on the price.

The second story is that some subjects were re-trading to manipulate the market. We explore this story below.

The third story – that subjects did not take correctly into account the true continuation probability – has less clear predictions. At the end of each period, one subject shook a die and announced the result of the die roll. It should have been clear that the probability of a sequence ending at the end of any period was constant and equal to ⅙. However, they could have been prone to the Gambler's Fallacy, thinking that if a '6' had not come up for a long time then it was more likely to come up soon. Since the equilibrium price is positively dependent upon the continuation probability, and hence negatively dependent on the stopping probability, a misperception of the probability could lead to a misperception of the price. Or to put it in more pragmatic terms, if a particular sequence had continued for many periods, then subjects would be getting increasingly nervous about it stopping soon and therefore increasingly reluctant to hold the asset. This would make the price a decreasing function of the number of periods for which a sequence had continued. Let us denote this latter variable by *pniq*. Here one hypothesis is that the price is a *decreasing* function of *pniq*.

However, there is an opposing story: as a particular sequence continued, subjects may have either got lulled into a false sense of security that it would keep on continuing, or they would grow increasingly suspicious of the unbiasedness of the die, or the 'unbiasedness' of the subject rolling it. In this case we would see that that the price would be an *increasing* function of *pniq*.

The price may also have been sensitive to the payment function. To test this we include a payment function dummy, *pfd*, which takes the value 0 for the step function sessions and the value 1 for the concave function sessions.

We obtain the following regression results, including the Volume of Trade, the gender of the buyer and that of the seller as additional potential explanatory variables. These regressions are over all transactions within the sessions.

Asset market sessions:

$$Price_t = \underset{(85.8)}{8.2} + \underset{(28.8)}{.008}\, hhit_t + \underset{(16.8)}{1.2}\, GS + \underset{(11.6)}{.8}\, GB - \underset{(-8.29)}{.501}\, VoT_t + \underset{(8.42)}{.075}\, pniq - \underset{(-45.4)}{3.28}\, pfd \qquad \overline{R}^2 = .586$$

(t - stats in parentheses)

GS: Gender of Seller; *GB:* Gender of Buyer; *VoT:* Volume of Trade; *pniq:* Period Number in Sequence

Credit market sessions:

$$Price_t = \underset{(155.7)}{1.28} - \underset{(-21.0)}{.0000004}\, hhit_t - \underset{(-4.13)}{.028}\, GS - \underset{(-4.57)}{.034}\, GB - \underset{(-1.73)}{.001}\, VoT_t + \underset{(13.2)}{.0011}\, pniq - \underset{(-6.57)}{.050}\, pfd, \;\; \overline{R}^2 = .138$$

(t - stats in parentheses)

GS: Gender of Seller; *GB:* Gender of Buyer; *VoT:* Volume of Trade; *pniq:* Period Number in Sequence

It will be seen that all variables (except for the Volume of Trade in the credit sessions) are highly significant. We note that the goodness of fit is worse for the credit market sessions, which merely reflects the fact that prices in those sessions were closer to the equilibrium[12].

As predicted, *hhit* has a positive impact in the asset market sessions and a negative impact in the credit market sessions, suggesting that the markets were not competitive. The *Volume of Trade* has a negative impact, reinforcing this non-competitive interpretation. The variable *pniq* has a positive impact in both markets, suggesting that our alternative explanation (subjects were lulled into a false sense of security) is the more likely one. The payment function dummy, *pfd*, has a negative impact, implying that prices were lower in the concave sessions. The impact of the gender variables[13], *GenderSeller* and *GenderBuyer*, are both positive in the asset market sessions and both negative in the credit market sessions. We have no explanation for this.

7. Re-trade

The efficiency in the Asset market and the Credit market deserves a second look. The experimental literature suggests that speculation can have an impact on efficiency, and possibly on mispricing (Lei *et al* (2001), Dickhaut *et al* (2012), Gjerstad *et al* (2015)). These studies compare the treatment in which subjects have the possibility to re-trade purchased securities with the treatment in which subjects are specialized as buyers or sellers without the opportunity to re-trade within the period. As pointed out in the literature section of our paper, these studies conclude that the option to re-trade within the period has no significant impact on mispricing but does have a negative impact on efficiency.

Our experimental design is different from these studies, since buyers and sellers have the opportunity to re-trade in the market within the period in all treatments. Our design is related to these studies because our subjects should have no reason to re-trade due to the heterogeneous endowments and end-of-period consumption. In the equilibrium solution, trading is specialized, and re-trade therefore should not occur in our experiment:

[12] As the equilibrium price is constant throughout all sessions, the intercept is picking up its effect.
[13] Taking the value 0 for a female and 1 for a male for both variables.

- A subject type who has more than 79 current tokens in the period should be a seller of the excessively owned tokens to increase his next period assets/tokens. This type of subject thus specializes as a buyer of assets (or next period tokens in the Credit market), in equilibrium.
- A subject who has fewer than 79 current tokens should be a seller of assets (next period tokens) to increase the number of her current tokens. She should specialize as seller of assets.
- If a subject has 79 current tokens, the subject does nothing in equilibrium.

In this section we look at the re-trade ratio of subjects. For that purpose, we count the units bought by net-sellers, denoted UB_t^S , and the units sold by net-buyers, denoted US_t^B .[14] We define the re-trade ratio in period *t* by the sum of the two relative to the total units purchased by the net-buyer, denoted UB_t^B , plus the total units sold by the net-seller, US_t^S .

$$RTR_t = \frac{US_t^B + UB_t^S}{US_t^S + UB_t^B}$$

Example. Assume there are 2 traders. Suppose one is a net buyer - buying 10 units net - and the other one is a net seller - selling 10 units net. But to get there the net buyer buys 15 units and sells 5 of them and for the net seller to get there he sells 15 and buys 5 back. Then 15 units were bought by the buyer, sold by the seller, including the 5 re-traded ones, the buyer's US^B is 5 and the seller's UB^S is also 5. Then the re-trade ratio measure is 10/30 = 1/3. If instead the net-seller sells 30 and buys back 20, and the net-buyer vice versa, the re-trade ratio is 40/60 = 2/3. Finally, if both traders sell and buy 15 units, the re-trade ratio is 30/30 = 1.

The re-trade ratio is substantial in the asset market; the average is 0.279 across all periods and sessions. It is significantly larger in the Step Asset Market than in the Step Credit Market (p-value of T-test 0.070) but not significantly larger in the Concave Asset Market than in the Concave Credit Market (p-value of T-test 0.206). The following result manifests the relationship of re-trade with efficiency and with mispricing.

Result 3 (Re-Trade): Efficiency decreases in the re-trade ratio, while mispricing does not increase.

[14] A net-seller in a period is defined as a subject who sells more units than he buys, and a net-buyer purchases more units than she sells.

Result 3 indicates that speculation as measured by the re-trade ratio can have a significant effect on efficiency as measured by the average payoff. Mispricing as measured by the relative absolute deviation, on the other hand, is not significantly increasing in the re-trade ratio. Both results are in line with the findings of the experimental literature.

To support Result 3, we report the following OLS regressions of efficiency (as measured by the average payoff per subject and period) and of mispricing (as measured by the relative absolute deviation) on the re-trade ratio. The significant slope vis-à-vis average payoff indicates that the re-trade ratio is a significant determinant of efficiency whereas the insignificant slope vis-à-vis the relative absolute deviation indicates no significant positive effect on mispricing, respectively.

Across all sessions (Average payoff per period (AvgPayoff)):

$$AvgPayoff_t = \underset{(41.8)}{.768} - \underset{(-8.20)}{.471}\, RTR_t + \underset{(4.96)}{.487}\,(RTR_t \times CM) \qquad \overline{R}^2 = .210$$

(t - stats in parentheses)

RTR: re-trade ratio; CM: Credit-market indicator variable {0,1}

Asset market sessions:

$$AvgPayoff_t = \underset{(18.7)}{.659} - \underset{(-2.25)}{.213}\, RTR_t \qquad \overline{R}^2 = .022$$

(t - stats in parentheses)

RTR: re-trade ratio

Credit market sessions:

$$AvgPayoff_t = \underset{(52.5)}{.835} - \underset{(-3.17)}{.288}\, RTR_t \qquad \overline{R}^2 = .049$$

(t - stats in parentheses)

RTR: re-trade ratio

Across all sessions (Relative absolute deviation (RAD)):

$$RAD_t = \underset{(8.35)}{.459} - \underset{(-0.65)}{.112}\, RTR_t - \underset{(-3.92)}{.1153}\,(RTR_t \times CM) \qquad \overline{R}^2 = .037$$

(t - stats in parentheses)

RTR: re-trade ratio; CM: Credit-market indicator variable {0,1}

8. Conclusions

The key results from this experiment are that subjects do seem to manage to consumption smooth and that prices do approach the equilibrium. These key findings are similar to the results from Crockett *et al* (2017), though our experiments generalise theirs in going from an oscillating formulation to a cyclical formulation. Moreover, we extend their analysis by analysing also a credit market, which appears to be the first implementation in the laboratory of the Bewley model of incomplete markets (Ljunqvist and Sargent 2004).

Interestingly, performance in both these key aspects (consumption-smoothing and equilibrium-pricing) is better in the credit market. Our data analysis shows that increased speculation measured by the re-trade ratio could be a source of the relatively low efficiency in the asset market, and that concentration of holdings (indicating the use of monopoly power) also affects efficiency.

We do, however, observe mispricing. We suggest three reasons for this: uncompetitive behaviour, re-trading (which may be a consequence of uncompetitive behaviour) and misperception of the stopping probability. All three were found to have merit.

The bottom line would appear to be that an asset market can help people to consumption-smooth, but that a credit market does it better.

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Table 1: Asset Market Parameters and Equilibrium

	Variable	Type 1 subjects	Type 2 subjects	Type 3 subjects
periods 1, 4, 7, …	***Initial assets***	***0***	***5***	***5***
	Dividend income from initial assets	0	10	10
	Units of the asset sold	-3	2	1
	Income from selling assets	-30	20	10
	Next period assets	3	3	4
	Tokens income	**109**	**49**	**59**
	End-of-period tokens	79	79	79
periods 2, 5, 8, …	Initial assets	3	3	4
	Dividend income from initial assets	6	6	8
	Units of the asset sold	2	-4	2
	Income from selling assets	20	-40	20
	Next period assets	1	7	2
	Tokens income	**53**	**113**	**51**
	End-of-period tokens	79	79	79
periods 3, 6, 9, …	Initial assets (trees)	1	7	2
	Dividend income from initial assets	2	14	4
	Units of the asset sold	1	2	-3
	Income from selling assets	10	20	-30
	Next period assets	0	5	5
	Tokens income	**67**	**45**	**105**
	End-of-period tokens	79	79	79

Items in **bold** are exogenous
Items in ***bold italics*** are exogenous in the first period of a sequence.

Table 2: Credit Market Parameters and Equilibrium

		Type 1 subjects	Type 2 subjects	Type 3 subjects
periods 1, 4, 7, …	**Tokens Income**	**109**	**59**	**69**
	Receipt from making credit contract	-30	20	10
	End-of-Period tokens	79	79	79
periods 2, 5, 8, …	**Tokens Income**	**53**	**123**	**61**
	Receipt from delivering on credit contract	36	-24	-12
	Receipt from making credit contract	-10	-20	30
	End-of-Period tokens	79	79	79
periods 3, 6, 9, …	**Tokens Income**	**67**	**55**	**115**
	Receipt from delivering on credit contract	12	24	-36
	End-of-Period tokens	79	79	79

Items in **bold** are exogenous

Table 3: Experimental treatments – number of sessions each with 12 subjects

		market	
		asset	credit
Payment function	step	4	4
	concave	4	4

Table 4: Consumption smoothing – average payoff per period and efficient consumption share

Consumption: Treatment:	Average payoff per period ([a]Significantly larger than the no-trade outcome according to a one-tailed t-test)	Efficient consumption share
SA Step Asset Market	.73***	.068
SC Step Credit Market	.86***	.288
CA Concave Asset Market	.45**	.005
CC Concave Credit Market	.73***	.057
Two-tailed two-sample t-test results:[a]		
p-value re treatments SA vs SC	.004***	.007***
p-value re treatments CA vs CC	.005***	.046**
p-value re treatments SA vs CA	.004***	.160
p-value re treatments SC vs CC	.007***	.000**

[a]significant test-result: $p < .01$***, $p < .05$**

Table 5: Equilibrium, Average price and mispricing

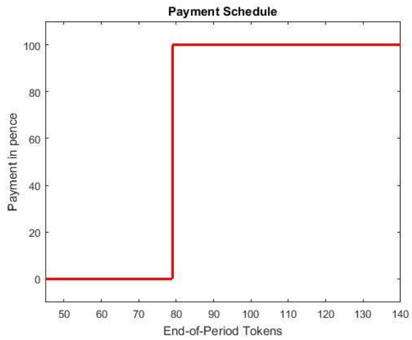
Treatment: Price:	Equilibrium price	Average price ([a]Significant differences from equilibrium price indicated)	Absolute relative Deviation $T^{-1}\sum\|p\text{-}Ep\|/Ep$
SA Step Asset Market	10.0	15.439	1.907
SC Step Credit Market	1.2	1.292	.189
CA Concave Asset Market	10.0	9.97	.372
CC Concave Credit Market	1.2	1.295	.151
	Two-tailed two-sample t-test result:[a]		
p-value re treatments SA vs SC			.543
p-value re treatments CA vs CC			.438
p-value re SA&SCvsCA&CC			.490

[a]significant test result $p < .01^{***}$, $p < .05^{**}$, $p < .10^{*}$

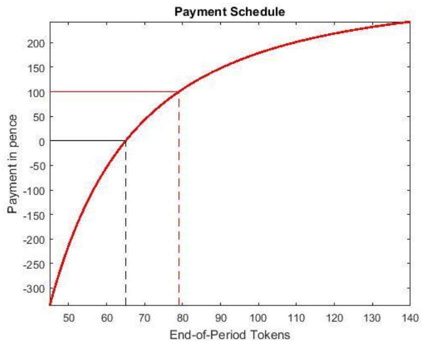
Table 6: Summary of Regression Results 'Explaining' the Transaction Prices, session by session

Session	Constant	hhit	Gender Seller	Gender Buyer	Volume of Trade	Period Number in Sequence	R-bar squared
SA1	7.73***	-.003	-.138	-.286	.635***	.563***	.120
SA2	8.04***	-.011***	all female	all female	.290***	.142***	.119
SA3	8.51***	.010***	.021*	-.217	.157	.216***	.315
SA4	23.7***	.013***	3.27***	1.99***	-8.13***	.398***	.274
SC1	1.27***	.00000005***	.069***	.003	-.002	.017**	.101
SC2	1.16***	.0000002***	-.004	-.050***	.012***	.082***	.231
SC3	1.37***	-.0000005***	-.079***	-.047	.002	.079***	.274
SC4	1.24***	-.00000003*	.194**	-.037	.000001	.002	.078
CA1	8.56***	.010***	-.233*	-.018	.278***	-.310***	.566
CA2	7.64***	.004	-.063	.904*	-1.92***	.451*	.447
CA3	6.97***	.0004***	.046***	-.051***	.048***	-.008**	.315
CA4	8.58***	.002***	.156***	-.261***	.072	-.099***	.363
CC1	1.05***	.0000003	-.009	-.007	.0001	-.003	.020
CC2	1.31***	.000005**	.069**	.036	-.003	-.042*	.057
CC3	1.13***	.00000002	.027	-.024	-.002	-.009	.300
CC4	1.29***	-.00000006**	.007	-.032*	-.011***	.012***	.460

Figure 1: The conversion scales from tokens to money.

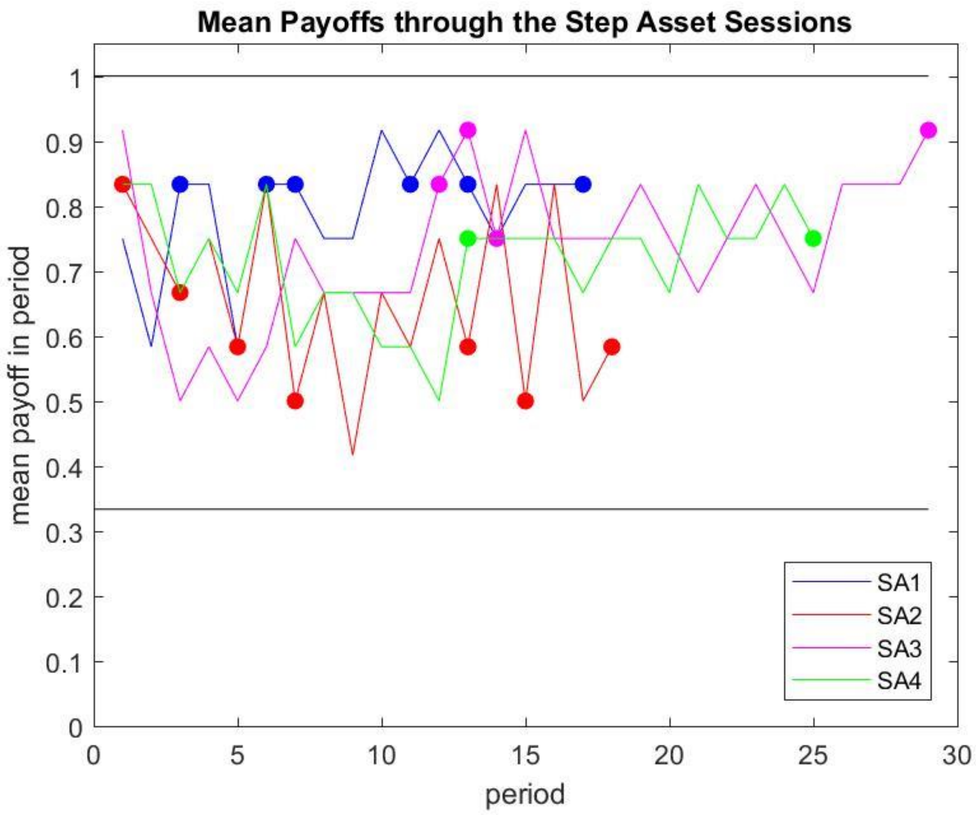


Treatment 1



Treatment 2

Figures 2: mean payoffs in the asset market sessions
Note: a filled-in circle indicates the end of a sequence



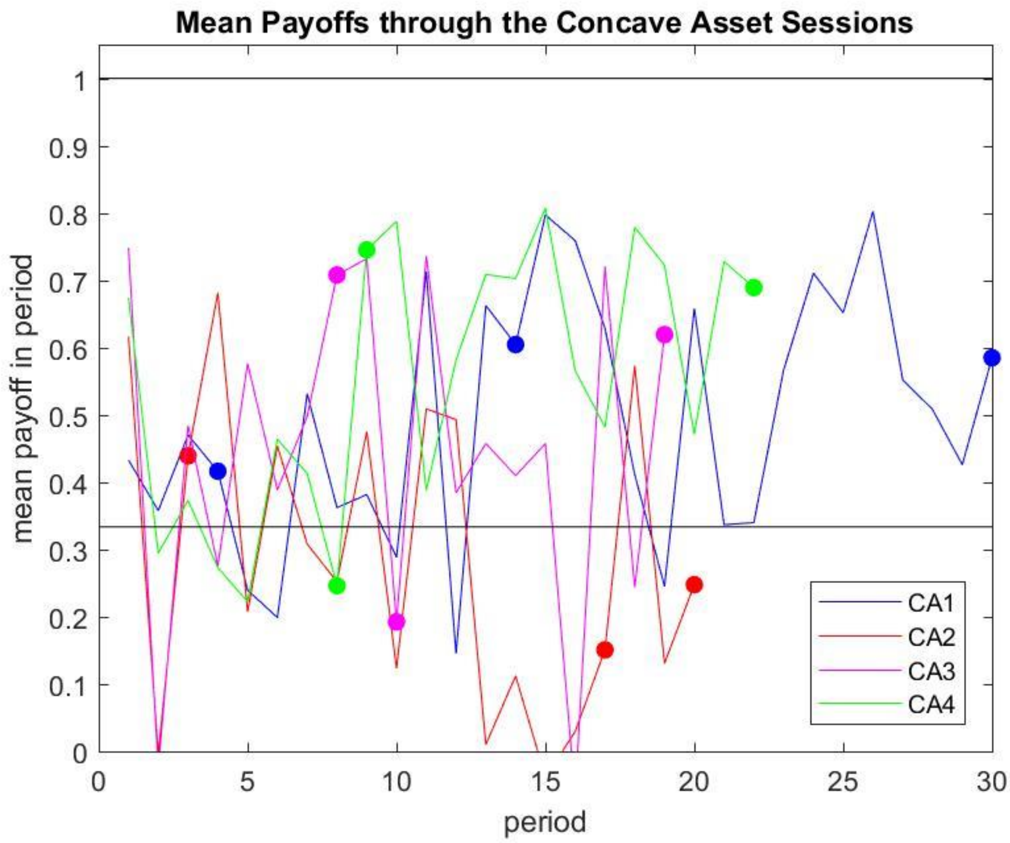


Figure 3: mean payoffs in the credit market sessions
Note: a filled-in circle indicates the end of a sequence

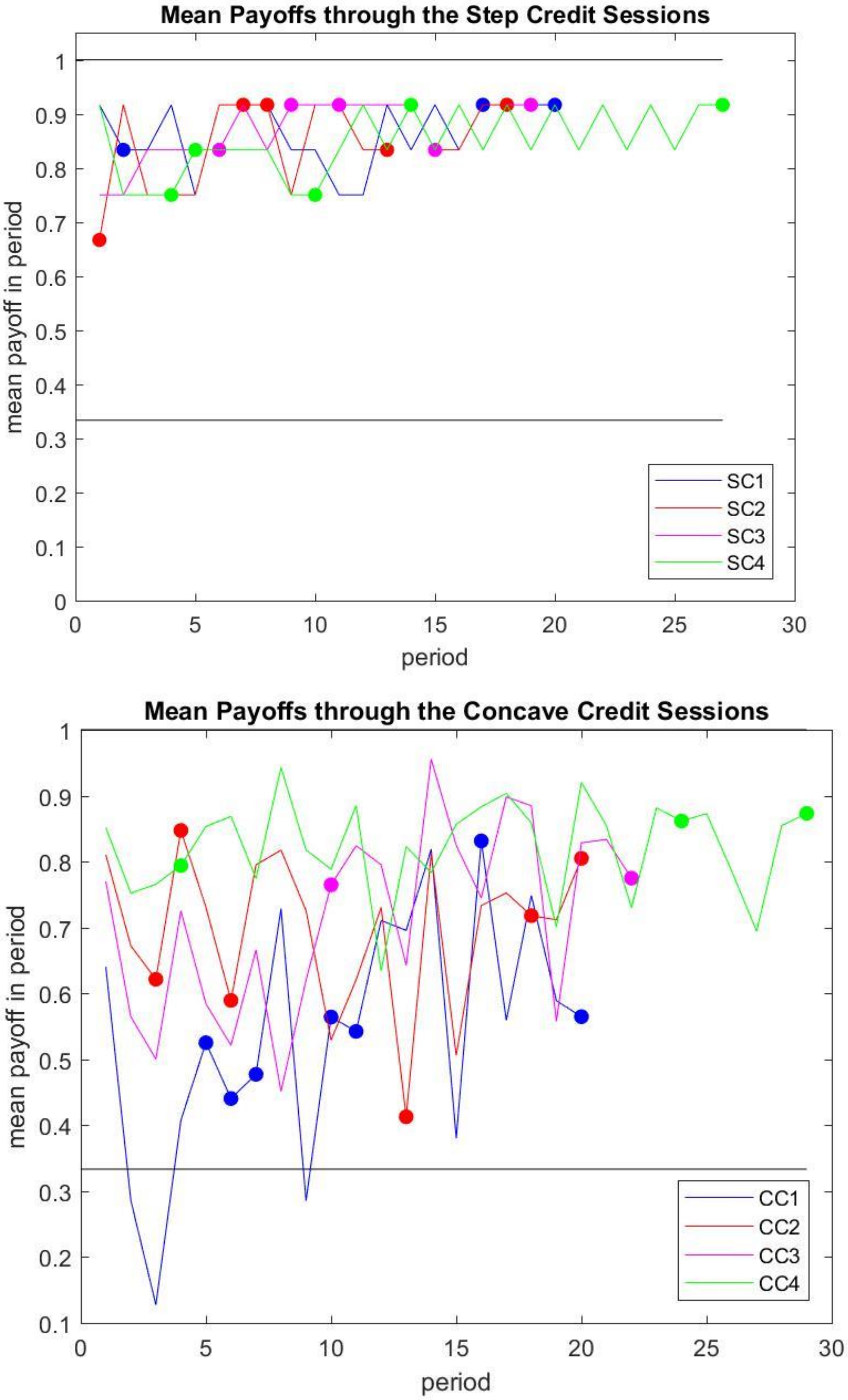
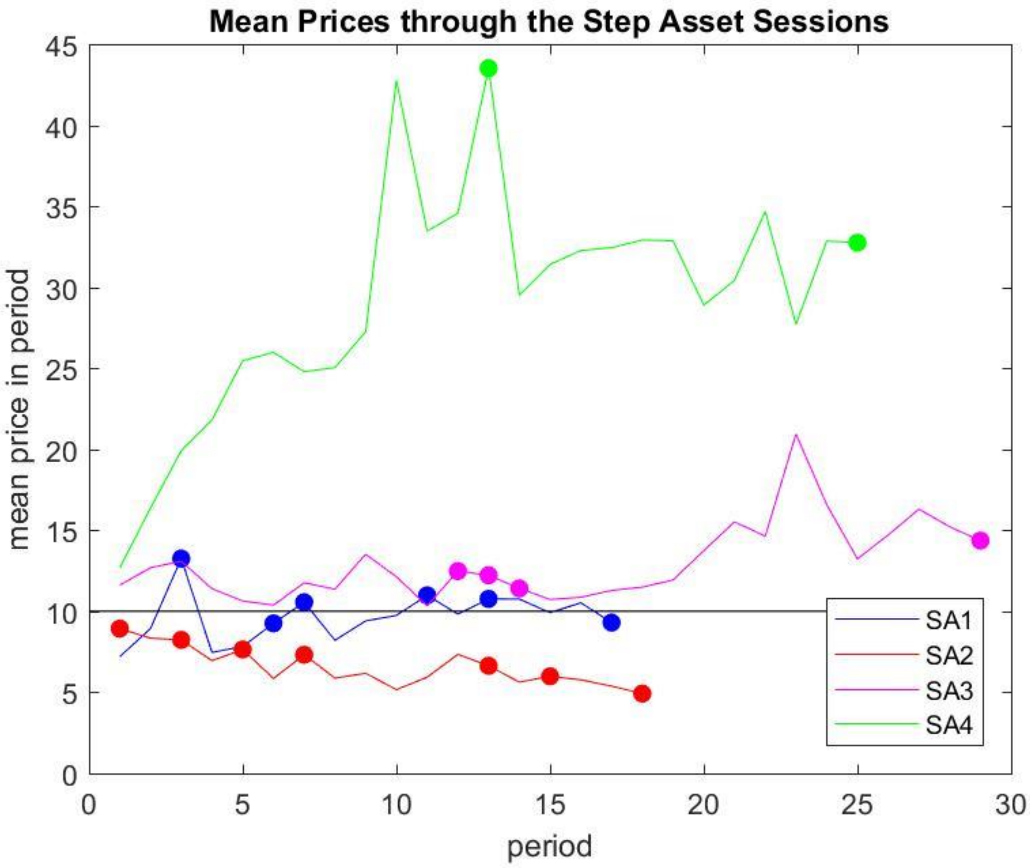


Figure 4: Mean Prices in the asset market sessions
Note: a filled-in circle indicates the end of a sequence



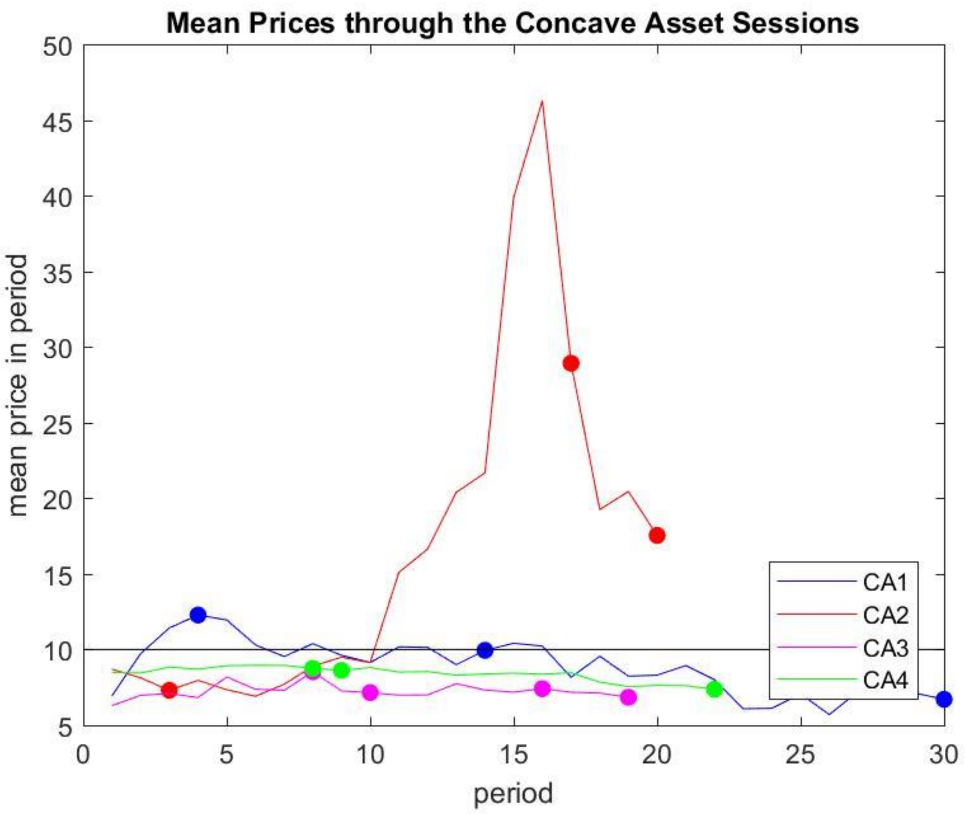


Figure 5: Mean Prices in the credit market sessions
Note: a filled-in circle indicates the end of a sequence