An Experimental Comparison of Two Exchange Economies: Long-Lived Asset versus Short-Lived Asset

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Abstract

The Lucas (1978) Tree Model lies at the heart of modern macro-finance. At its core, it provides an analysis of the equilibrium price of a long-lived asset in an exchange 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* (2018), Asparouhova *et al* (2016) and Halim *et al* (2016), all of them using a particular instantiation of the Lucas Model. Here we adopt a different instantiation to the first two, extending their analyses (like Friedman *et* al (1984)) from a two-period oscillating world to a three-period cyclical world; this is partly to test the robustness of their results. We also go one step further, and compare this solution (to a consumption-smoothing problem), in which consumption claims are traded via the long-lived asset, with the alternative solution provided by a market, in which agents can directly trade (short-lived) consumption claims between periods. We find that the latter exchange economy is more efficient in encouraging consumption smoothing than the economy with the long-lived asset. We find evidence of uncompetitive trading in both markets.

Keywords: Asset Market Experiment; Lucas Tree Model; Bewley Incomplete Markets; Intertemporal Choice; Exchange Economy; General Equilibrium; Consumption Smoothing; Credit Market; Herfindahl Index; Term Structure of Sharpe Ratios.

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1. Introduction

The motivation of this paper is to study and compare the performance of two exchange economies, one for a long-lived asset and the other one for a short-lived asset (in both of which agents can indirectly or directly trade consumption through time) with respect to two intertwined key items of interest: (1) whether agents smooth their consumption through time; (2) whether the market manages to reach its equilibrium price.

We start with an experimental test of a particular instantiation of the Lucas (1978) tree model. In its simplest form this model considers an infinite discrete-period world in which there is perishable money (apples) and a long-lived asset (the tree) 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, that is the way we induce preferences for consumption smoothing and trading in the experiment, it is desirable for end-of-period money holdings to be smoothed through time. This can only be achieved by individuals trading the long-lived 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* (2019), Asparouhova *et al* (2016), Halim *et al* (2016). All these three papers use oscillating 2-cycle fixed incomes to induce motives for trade. Crockett *et al* (2019) and Halim *et al* (2016) have a long-lived asset with a fixed dividend as the only means of smoothing consumption through time. Asparouhova *et al* (2016) have two long-lived assets, one with a stochastic dividend and the other one being a fixed income security, where both can be used to smooth consumption. We advance the literature by using 3-cycle incomes, which increases the complexity of the problem faced by the subjects, and tests the robustness of previous results.

Further, we take the idea of the Asparouhova *et al* (2016) paper of two assets and split them between two treatments (having one bond-like and one stock-like asset but both involving fixed income streams like the other two papers), so that we can isolate the comparative static impact of asset duration on price relative to fundamental value.

Splitting the asset duration by treatment, along with the step function simplification (which we shall describe shortly), allows us to see in the data to what extent asset complexity and induced payoff complexity impede convergence to fundamental value, and how much relative noise is involved in that process. We report important comparative static results. Our treatments have significant implications in intuitively understandable and interesting directions. It is important and interesting that the markets achieve regularities by treatment despite the increased complexity of a 3-cycle income environment.

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 long-lived asset which pays in every period a constant dividend, i.e., a fixed amount of (perishable) money. In each period each agent gets, in addition, a time-varying (and deterministic) endowment of 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 (long-lived) asset market solution (to a consumption-smoothing problem) with an alternative market for a short-lived asset which we call the 'credit market'[1]. In this market, agents can directly trade consumption in the current period (apples) for claims of consumption in the next period (future apples). With our experimental data, we evaluate the Sharpe ratios of asset returns of short-term and long-term assets in a between-subjects setting. In contrast to the declining term-structure of real-world Sharpe ratios with maturity (van Binsbergen, Brandt and Koijen 2012, van Binsbergen and Koijen 2017), we find no such decline with our assets.

In summary, this paper contains three major differences from the previous literature: (1) we extend the two-period (oscillating) framework of Crockett *et al*, to a three-period (cyclical) framework; (2) we compare behaviour in the asset market with that in a credit market; (3) we also examine the effect of changing the payoff function from a concave function to a step function. We briefly explain why we have done these three things.

Our move to a three-period (cyclical) framework follows that of Friedman *et al* (1984). They simply state that they "extend that analysis to 3-period asset markets", we suspect to test the robustness of their results. It is well known that decision-makers have problems in solving dynamic decision problems, and are notoriously myopic. The oscillating case studied by Crockett *et al* (2019) is relatively simple: in the steady state, decision-makers only have to plan one period ahead; in the

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

cyclical case they have to plan two periods ahead and backwardly induct from 2 periods hence. If one looks at the optimal strategies in Tables 1 and 2, the solution is by no means obvious, even in structure: buying in 2 periods and selling in 1, or buying in 1 period and selling in 2. Note also that the two-period cycle studied by Crockett *et al* (2019) is the simplest possible environment of its class, so it is important to study whether consumption smoothing continues to happen if the environment gets more complicated.

Our extension to a comparison of behaviour in an (long-lived) asset market with that in a (short-lived) credit market is motivated by the idea that the equilibrium is more obvious in the latter: the expected value calculation for the short-lived asset is straightforward for subjects as we explain in section 3. In contrast, the calculation of equilibrium in the (long-lived) asset market requires the computation of the expected value of future dividends over an infinite horizon.

We have not yet mentioned our extension to a step payment function. This will be described in detail later, but it is simple to describe: with this, the mapping from end-of-period token holdings into money for the subject is a step function with a single step (see the left-hand graph in Figure 1) – above this step payment is £1, below it £0. This is effectively telling the subjects that the best thing to do is aim for end-of-period token holdings equal to the step[2]. We deliberately fix this step at the equilibrium level. Note that this is not telling them *how* to get to equilibrium – which is the whole point of the trading – but to see if the market can converge to the equilibrium when all subjects know what the equilibrium is. We isolate the equilibrium from the problem of achieving it.

This paper starts with a literature review. We then outline the exchange economy model with the long-lived asset, 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 solution for the exchange economy with the short-lived asset. 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 markets which has enhanced our understanding of price formation in asset markets. Early studies like Plott and Sunder (1982), Forsythe *et al* (1982), Friedman *et al* (1984), motivated agents to trade by providing heterogeneous

[2] The step function implies stronger marginal buy/sell incentives, pushing subjects towards consumption smoothing. In a high-income period, a subject starts with extra cash (more than 79) that is worthless unless shifted to the next period, whereas in a low-income (less than 79) period, the subject has a very strong incentive to acquire more cash in the current period to reach the threshold.

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 Plott (2002), Asparouhova *et al* (2003) and Bossaerts *et al* (2007).

Another relevant strand of experimental literature concerns 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 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 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* (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 continuing probability of 5/6. 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 two important differences in their design to ours and also to that 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.

Crockett *et al* (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 Crockett *et al* (2019), 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[3].

Noussair and Popescu (2019) also contribute to the experimental literature on the Lucas tree model. Their design involves two long-lived assets with stochastic dividends to study the research question whether asset prices co-move with another when an independent shock occurs to one asset but not to the other. Noussair and Popescu report evidence for co-movement in line with theory, but report a price drift of the non-shocked asset beyond the theoretical prediction.

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)[4]. In this model, the consumer's labour income is subject to a shock. A riskless short-term asset facilitates individual consumption smoothing between periods. Our exchange economy involving short-lived asset claims shares important features with the Bewley model, and leads to identical equilibrium consumption as the Lucas tree model in our design. Thus, we are able to compare consumption smoothing and pricing in markets with long-lived versus short-lived securities. We are not aware of any other study that investigates the pricing and consumption smoothing with short-lived asset claims in the laboratory. Van Binsbergen and Koijen (2017) show that the real-world term structure of returns is downward sloping in maturities across various asset classes including bonds and equity. Their finding is at odds with the standard model which suggests non-decreasing expected returns. In contrast, our laboratory results on Sharpe ratio structure are not in conflict with the standard model.[5]

3. Background Theory

[3] 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.

[4] 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.

[5] Bosch-Rosa (2017) studies rollover risk of maturities in a bank-run-type of laboratory experiment. The data suggest that short-term maturities behave less vulnerable in economic downturns than long-term maturities. The absence of macroeconomic cycles in our experiment could potentially explain why the Sharpe ratio in our short-lived security does not exceed that of our long-lived security.

We start by describing the exchange economy of the long-lived security, before we turn to that of the short-lived security. We confine our discussion to one repetition of the Lucas tree 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 (apples), and a durable asset (the tree), 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 exchange 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 aggregate 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

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

where a_t is the asset holding at the beginning of period t and p_{Lt} is the price of the asset in period t. The optimising decision for any (risk-neutral[6]) 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

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

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 $p_{Lt} = E_t\beta(p_{Lt+1}+d)$.

In a stationary equilibrium $p_{Lt}=p_{Lt+1}=p_L$ and hence

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

This is the constant steady-state equilibrium durable asset price which implies constant equilibrium returns in our setting. It has the obvious interpretation as being the discounted dividend income from holding one unit of the asset.

[6] Note that $u(.)$ is *not* the DM's utility function over money, but is the conversion (into money) of the end-of-period consumption. Crockett *et al* (2019) explore the effect of the DM having a concave function over money earned in the experiment. They show that this implies a *lower* equilibrium price than that derived here. This may explain some of our experimental findings.

We now consider the exchange economy featuring the short-lived security. We will refer to this as the credit market. In this, agents exchange, at some price, perishable money units (apples) in one period for a promise of money units in the following period (future apples). Let us assume a constant credit market price p_S. If an individual wants to buy s_t money units in period *t,* promising to pay back s_{t+1} money units in period $t+1$, then, at the price p_S, he or she will have to pay back $p_S s_t = s_{t+1}$ money units in $t+1$. The first order condition for the choice of s_t in period t is

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

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

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

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

This is the constant steady-state equilibrium credit price (that is, the short-lived asset price). It has the obvious interpretation[7]: in equilibrium, one unit of money in period t is exchanged for p_S 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. The reasoning is straightforward: if I sell one unit today for p_S tomorrow (the price being denoted by p_S), my expected return is equal to βp_S (where β is the continuation probability). Thus for a risk-neutral agent we need $1=\beta p_S$, and hence $p_S = 1/\beta$, in equilibrium.

4. The Experimental implementation

There were 12 subjects in each experimental session. Sessions involved *either* the (long-lived) asset market *or* the credit (short-lived asset) market; no subject participated in both. The session started with one of the experimenters reading aloud over the tannoy[8] system the Instructions for the experiment[9], 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

[7] This short-term price terminology, which is somewhat unusual for a credit instrument, is in line with our experimental implementation. We chose this implementation to give the predicted equilibrium price a chance to prevail as transaction price in the experiment. Standard discounting terminology, which we have applied to the long term asset, would require the statement of today's price in exchange for a promise of one cash-unit tomorrow. The equilibrium price in this formulation would equal the continuation probability of (5/6) in the experiment, which cannot prevail as transaction price in the market as subjects enter their limit orders in decimals.

[8] A loudspeaker system in the laboratory, so that all subjects could hear.

[9] They can be found on the website devoted to this experiment.

were answered. Afterwards, each subject individually watched a video[10] describing the *trading mechanism*. Subjects were then asked if 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 trading mechanism can be summarized as follows. Subjects submitted limit orders to buy or sell. The limit order stated a number for a price and a number for a quantity. Both numbers could include decimal places. For limit order submission in the asset market, there were two price/quantity trading masks, one for sells and one for buys. In the credit market, subjects had the same two price/quantity masks as in the asset market, but additionally they had two quantity/quantity masks. In the quantity/quantity masks, which they could use alternatively for order submission, subjects detailed the quantity of current tokens and the quantity of next period tokens in exchange.[11] Outstanding limit orders were visible onscreen to all subjects in the order book, always reported in price/quantity display, ordered by price.[12] Limit orders of equal prices were ordered chronologically by the time of arrival. Transactions were immediately executed upon arrival of a marketable limit order at the price of the outstanding limit order. Unfilled parts of an outstanding limit order stayed in the order book.

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[13] (Fischbacher 2007), for recruitment we used HRoot (Bock et al. 2014). 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[14].

In each period of the experiment, subjects were endowed with an income denominated in *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

[10] Again available on the website.
[11] For inexperienced subjects the quantity/quantity mask was apparently useful. It was the more frequent choice for order submission in the first five periods (50.7-57.6 percent of limit orders). On average, however, subjects chose more frequently to submit their orders through the price/quantity mask (54.9 percent).
[12] A subject could submit an unlimited number of buy and sell orders to the market. The latest submission would be outstanding in the order book until filled or replaced with a new limit order of the submitter.
[13] The program can be found on the site, as can the questionnaire administered at the end of the experiment.
[14] 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.

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' (Treatment 1) and the 'concave payment function' (Treatment 2). 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. With the step payment function, the marginal gains of a subject are infinite in the vicinity of 79 tokens if her end-of-period balance falls short of 79 tokens, and are zero beyond that point. In contrast, with the concave payment function, the marginal gains are smooth around the 79 tokens benchmark.

In order to explain our choice of these two payment functions, 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 (long-lived asset) 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 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. It could be argued that the step payment function makes the problem more transparent; indeed that was our main reason for introducing it. There are two elements to the solution: (1) realising that consumption-smoothing is optimal; (2) calculating the level of consumption at which to smooth. Treatment 1 effectively tells them the answer to (2); and strongly hints at the answer to (1). It is of interest to see whether the subjects responded to these hints.

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 (short-lived asset) 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. Main results

In total 288 subjects participated in the experiment: 12 subjects in each of six independent sessions for each of the four treatments. The subjects' average age was 22.23, the average CRT-score was 1.46,[15] and 56.60 percent 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.

Result 1 (Consumption smoothing). *A. Consumption smoothing is observed in each treatment. B. 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 and 3 show the average payoffs in each period of each session of the experiment. Table 4 summarises the average payoff by market and by payment function. The efficient consumption level

[15] 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 2019). 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?

in the experiment was 79 tokens which implied a payoff of £1 per period. The no-trade consumption level implied a mean payoff per period 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.

A. The observed average payoff levels significantly exceed the no-trade consumption level in each market and for each payment function (see Table 4).

B. The average payoffs 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 Mann-Whitney tests are indicated in the bottom lines of Table 4.[16] In the first column of Table 6 we report further supportive evidence of the stated treatment effects from a dummy regression with robust standard errors.

Result 2 (equilibrium pricing). A. *Close-to-equilibrium pricing is observed in both the asset and credit markets and with both the step and the concave payment functions. B. The asset market deviations from the equilibrium price are larger in magnitude than in the credit market.*

A. Figures 4 and 5 show the average price trajectories and the equilibrium price for each treatment condition. Table 5 records the average prices, the average of the relative deviation and the average of the absolute relative deviation from the equilibrium price. These are standard measures in the experimental asset market literature to identify mispricing (see Stöckl *et al* 2010). The relative deviation and the relative absolute deviation are defined as follows.

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

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

[16] The differences between the Step Asset Market and the Concave Credit Market treatments are not significant; the p-values are .337 (average) and .109 (efficient consumption) respectively.

The average prices are recorded in Table 5[17]. In all treatment conditions, we observe no significant differences from equilibrium, as also indicted by the relative deviation. In the Step Asset Market the deviation is economically large, because the price in one market (session SA4, see Figure 5) deviates more from the equilibrium than the others. The two-tailed one-sample Wilcoxon test of the hypothesis of equilibrium pricing results insignificant at the 10 percent level; for the Step Asset Market treatment the p-value is .60. The recorded relative deviations suggest no significant differences between treatments. The p-values are recorded in the table.

B. There are differences in mispricing between treatments. The differences from the equilibrium prediction are suggested in the figures 4 and 5 by the spread around the prediction, which is apparently smaller in the credit market than in the asset market. The absolute relative deviations that measure these deviations from the equilibrium prediction are significantly smaller in the credit market than in the asset market. The *p*-values of the two-tailed two-sample Mann-Whitney are reported in Table 5. The payment function, on the other hand, has no significant effect on mispricing in terms of RAD, but the price level measured by RD seems a bit lower with concave payment. The regression analysis with robust standard errors reported in Table 6 underlines these observations.

Robustness check[18]: We have conducted the analysis in tables 4 and 5 on the data of the last sequence only, i.e., the sequence when subjects have the most familiarity with the setting. All reported significance levels in tables 4 and 5 are fully supported, in fact, significances tend to increase. There is one difference; the relative deviation from the equilibrium RD in the concave asset market is significantly different (smaller) from the one in the concave credit market. The Mann-Whitney test of this difference yields a p-value of .055, whereas it is .109 in Table 5.

We note, in looking at the period-by-period prices in Figures 4 and 5, that there appear to be bubbles (partly burst) in the Step Asset Sessions SA2 and SA5, and (burst) in the Concave Asset session CA2. We suspect that these deviations from equilibrium are due to hoarding; [19] we explore

[17] Note that in the Concave Asset Market and the Concave Credit Market average prices are *below* the equilibrium. This could be because our subjects were risk-averse with respect to the money earned in the experiment (see footnote 7 in section 3). Elsewhere (particularly in the Step Asset Market) Market average prices are *above* the equilibrium; this seems to be due to the bubbles which we discuss later.

[18] We appreciate that the results in this section and the next depend upon the stochastic specification implicit in the analyses; we have explored alternative specifications, and are happy that our results are robust.

[19] Crockett et al. (2019) suggested that some subjects hoarded assets, in particular, in the treatment with a linear payoff function.

this possible explanation in section 7. We also note that bubbles in the Credit Market sessions (Figures 4 and 5) are conspicuous by their absence.

6. Pricing uncertainty of future returns

One possible explanation for the larger deviations from the equilibrium in the asset market compared to the credit market is the uncertainty about pricing of future claims. This uncertainty impacts the long-term (asset) market differently from the short-term (credit) market. In the credit market this uncertainty does not exist, because the return of tomorrow is fixed today. The standard deviation of returns represents an ex-post measure of this uncertainty. The price for return uncertainty is frequently represented in the Sharpe ratio. The Sharpe ratio measures the risk-adjusted return of an investment, in particular, its (excess) return per unit of risk.

$$\text{Sharpe Ratio} = \frac{R - R_f}{\sqrt{VAR(R)}}$$

R denotes the return of the risky investment, R_f the return on the risk-free investment and the standard deviation of the risky return measures the risk of the investment. Standard theory suggests that investors prefer a high to a low Sharpe ratio. Since we have no risk-free rate in our experimental setting, we compute the Sharpe ratio as the ratio of return to standard deviation of the return. The return on the long-lived asset is the sum of capital gain yield and dividend yield, that is, $R_t = (p_{Lt} + d_t)/p_{Lt\text{-}1} - 1$. The return on the short-lived asset is simply the price minus cost, $R_t = p_{St\text{-}1} - 1$. In fact, these are the returns when the sequence does not expire in period t-1. If the sequence expires, the return is -1. Therefore, the expected return for both short-term and long-lived claims is 0 in our setup and the variance is 0.183.[20] The equilibrium Sharpe ratio is constant at zero for short-lived and long-lived claims. To estimate the Sharpe ratio from our data, we use the return on the average price of the period, and the standard deviations across all returns in a session. Note that the recent empirical literature reports a decreasing pattern of Sharpe ratios (van Binsbergen, Brandt and Koijen 2012, van Binsbergen and Koijen 2017). Van Binsbergen and collaborators attribute this decreasing empirical pattern of Sharpe ratios to the empirical risk of rare disasters which hits long-lived returns more than short-lived returns. In our setup, of course, risk of rare disasters is absent.

Result 3 (Sharpe ratio structure). The term structure of *Sharpe ratios is non-decreasing.*

[20] E(R) = .2 × 5/6 + (-1) × 1/6 = 0, and VAR(R) = $.2^2 \times 5/6 + (-1)^2 \times 1/6$, where .2 and -1 are the possible returns and 5/6 and 1/6 the corresponding probabilities. The standard deviation in equilibrium is thus .428.

Figure 6 shows the term structures of return, standard deviation and Sharpe ratio in our experiment. The corresponding numbers of average Sharpe ratios, the average returns and average standard deviations are recorded in Table 7 for each treatment. As indicated in the table, the Sharpe ratio deviates significantly from the equilibrium prediction in the concave payment asset market treatment. In the step level payment treatment the signs are the same, but statistical significance is not achieved at the 10 percent level. Overall, we find significantly higher Sharpe ratios for long-lived than for short-lived asset returns. The Sharpe ratios of short-lived asset returns are not different from the equilibrium prediction of zero.

Result 3 is rather opposite to the one reported in van Binsbergen and Koijen (2017): under laboratory conditions we failed to reproduce the declining pattern of term-structure of Sharpe ratios observed in real-world data (van Binsbergen and Koijen 2017). The likely reason is that our experimental design involves no rare disasters risks. The pattern in our data suggests that investors in the asset market request a premium for the uncertainty about future prices. Asparouhova et al. (2016, p. 2731) reach a related conclusion on the failure of rational expectations to predict price volatility observed in the data, given a complicated environment: “Agents have to form expectations about endogeneous uncertainty, [… whereas theory assumes] that agents know the (endogeneous) mapping from states to prices.”

7. Rationale for mispricing and efficiency losses

As pointed out above, the uncertainty of future prices impacts the long-term (asset) market differently from the short-term (credit) market. To insure against the uncertainty about future prices, subjects in the asset market could start hoarding assets. In the credit market, subjects have no opportunity to hoard the short-term claim, because the claim of today has ceased to live tomorrow.

A way to investigate non-equilibrium behaviour as hoarding is in the measurement of market concentration. Competitive equilibrium assumes a ‘sufficiently large’ number of participants. While many other, usually simpler, experiments have observed competitive behaviour with N = 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, which we denote by hhi_t;

$$hhi_t = \sum_{i=1}^{N} s_{it}^2$$

where s_{it} is the share of future claims of subject *i (=1..N) of outstanding claims at the end of the period*. In the asset market s_{it} is the subject's asset holding relative to 40 outstanding assets.[21] In the credit market, s_{it} is the subject's number of next-period tokens at the end of the period relative to the endogenous sum of all next-period tokens. One hypothesis therefore is that the price in the asset market may be an *increasing* function of hhi_t, leading to mispricing and allocative inefficiency.

Result 4 (Investor concentration). The Herfindahl-Hirschmann index helps to explain the differences between treatments in A. efficiency and B. mispricing.

A. In the first column of Table 8 we report regression results with robust standard errors that indicate the effect of investor concentration on efficiency. The result suggests that the difference between the asset market and the credit market can be reduced to the difference of the sensitivity of investor concentration. When the claims concentration is high in the asset market, the payoff is significantly reduced compared to the credit market. In Tables 8A and 8B we report the effect of share concentration for concave payment and step payment separately.

B. The third column in the Table 8, as well as in the tables 9A and 9B, show the dependence of mispricing in terms of the relative absolute deviation from equilibrium pricing on investor concentration. The result shows that investor concentration has a small but significant general impact on mispricing. However, this effect is significantly increased in the asset market treatment, as is revealed by the significance of the interaction effect. The interaction effect is particularly important in the asset market with the concave payoff function. Interestingly, the effect of the investor concentration seems to have a positive sign as is indicated in the second column where we report the impact of investor concentration on the relative deviation from equilibrium price. Thus the data suggest that asset market prices are higher when investor concentration increases.

[21] In equilibrium the hhi_t varies between periods. In the asset market the predicted three period hhi_t-cycle is {.085,.135,.125}, and in the credit market {.194,.139,n/d}.

In table 10 we show the average *hhi* numbers for each treatment and indicate the difference from the predicted *hhi* numbers. Interestingly, the deviations from the predicted values in the asset market are not higher than in the credit market. Yet, share concentration has a different impact in the market for short-term claims than in the long-term asset market.

We also looked at alternative explanations why efficiency and mispricing is worse in the asset market than in the credit market.[22] However, no alternative story captures the differences as well as the *hhi.* Our data suggest that asset duration, price volatility, and hoarding are closely related with another. The causality of this relationship could be an interesting question for future research.

8. Conclusions

The key results from this experiment on the Lucas tree model 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* (2019), though our experiments generalise theirs in going from an oscillating formulation to a cyclical formulation. Besides the market for long-lived assets, we extend their analysis by analysing also a credit market in which short-lived claims are traded. This appears to be a first implementation in the laboratory of the Bewley heterogeneous agent model (Ljunqvist and Sargent 2004). Since our experiment has no economic risk other than the continuation risk, both models imply the same equilibrium consumption vectors of agents.

Interestingly, performance in both these key aspects (consumption-smoothing and equilibrium-pricing) tends to be better in the credit market. Our data analysis shows that concentration of holdings (indicating the use of monopoly power) affects efficiency.

[22] For instance, we looked at subjects' re-trading of claims *within* a period which is a departure from the equilibrium prediction. In equilibrium, subjects trade the optimal quantity at the equilibrium price in order to smooth their consumption. In the experiment, some subjects buy and sell, that is, they re-trade claims of assets within the same period. Related literature suggests that re-trading of assets would be a symptom of speculation (Lei, *et al* (2001), Dickhaut *et al* (2012) and Gjerstad *et al* (2015)), and Hirota *et al* (2018) report that mispricing increases with the required number of re-trades across periods. In our experiment, the transaction volume is related to re-trading behaviour. Re-trade may not be independent of investor concentration. Importantly, we find that the significance of *hhi* at explaining deviations from equilibrium is apparently better than the one offered by the re-trading data of subjects. Therefore, we have decided not to report the data analysis on re-trade in the paper. We also looked at possible mistakes that subjects make at perceiving continuation probabilities. If subjects exhibit the *gambler's fallacy*, perceived continuation probabilities may decrease. To the contrary, if subjects exhibit the *hot-hand effect* perceived continuation probabilities can increase. Nonetheless, a regression of the overall data suggests no significant effect of sequence length on mispricing or efficiency. Finally, gender seems also to have no clear effect on efficiency and mispricing in our data.

We observe mispricing in the market of the long-lived asset. Our data suggest that uncompetitive behaviour, that is hoarding of assets, is a key source of this mispricing. For both pricing and efficiency, the market for long-lived assets results in larger deviations from the equilibrium than the market for short-lived assets.

The suggested reason for the larger deviations from the equilibrium in the asset market compared to the credit market is the uncertainty about pricing of future claims. This uncertainty impacts the long-term (asset) market differently from the short-term (credit) market. To insure against the uncertainty about future prices, subjects in the asset market may be motivated to hoard assets. In the credit market this uncertainty does not exist and subjects have no opportunity to hoard the short-term claim, because the claim of today has ceased to live tomorrow.

Our paper contributes to the discussion on the term structure of returns. The recent empirical literature observes a declining term structure of Sharpe ratios in real-world markets (van Binsbergen, Brandt and Koijen 2012, van Binsbergen and Koijen 2017). Van Binsbergen and collaborators report that this observation contrasts with the prediction of standard models that suggest no lower risk adjusted returns on long-term assets than on short-term assets. It seems interesting that under controlled laboratory conditions we find no declining term structure, in particular, because van Binsbergen and Koijen (2017) believe that the declining term structure could be key to the explaining of puzzles in finance as, for instance, related to equity premium and excess volatility. Future experiments shall address the question whether the term structure of returns reverts in the presence of disaster risk. This feature is absent from our study.

The main question of our study has been whether long-lived assets or short-lived assets are preferable for consumption smoothing. The bottom line would appear to be that a market for long-lived assets can help people to consumption-smooth, but that a market for short-lived assets 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	6	6
	concave	6	6

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 Wilcoxon signed-ranks test)	Efficient consumption share
SA Step Asset Market	.712**	.186
SC Step Credit Market	.855**	.519
CA Concave Asset Market	.452**	.012
CC Concave Credit Market	.742**	.076
Two-tailed two-sample Mann-Whitney test results:[a]		
p-value re treatments SA vs SC	.004***	.004***
p-value re treatments CA vs CC	.004***	.005***
p-value re SA&CA vs SC&CC	.001***	.030**
p-value re SA&SC vs CA&CC	.006***	.000***

[a]significant test-result: $p < .01$***, $p < .05$**; $p < .10$*; the one-sample Wilcoxon signed-ranks test is conducted on the independent cohort average ($n = 6$); the two-sample Mann-Whitney test is conducted on the independent cohort averages ($n_1 = n_2 = 6$).

Table 5: Average price and mispricing

	Average price (aSignificant differences of average price from equilibrium indicated)	Average Relative Deviation $\sum(p\text{-}Ep)/(T\ Ep)$ (aSignificant differences from equilibrium price would be indicated)	Avg Relative Absolute Deviation $\sum\lvert p\text{-}Ep\rvert/(T\ Ep)$
SA Step Asset Market	13.52	.440	.695
SC Step Credit Market	1.25	.037	.174
CA Concave Asset Market	8.34	-.160	.392
CC Concave Credit Market	1.15	-.038	.158
Two-tailed two-sample Mann-Whitney test results:[a]			
p-value re treatments SA vs SC		.873	.036**
p-value re treatments CA vs CC		.149	.010**
p-value re SA&CA vs SC&CC		.355	.002***
p-value re SA&SC vs CA&CC		.094*	.311

[a]significant test result p < .01***, p < .05**, p < .10*; the one-sample Wilcoxon signed-ranks test is conducted on the independent cohort average (n = 6) indicating no significant deviation from equilibrium; the two-sample Mann-Whitney test is conducted on the independent cohort averages ($n_1 = n_2 = 6$).

Table 6: Regression results on efficiency levels and mispricing of market institutions

	Dependent variable		
	Average Pay in period	Relative Deviation of average price from equilibrium in period	Relative Abs Deviation of average price from equilibrium in period
Constant	.713***	-.131	.096
	(29.6)	(-1.12)	(1.26)
AssetD	-.218**	.099	.380**
	(2.64)	(.50)	(2.64)
StepD	.181***	.332	.158
	(6.82)	(1.64)	(1.07)
#observations	534	534	534
#clusters	24	24	24
R-squared	.471	.078	.164

Significant test result is indicated as follows; $p < .01^{***}$, $p < .05^{**}$, $p < .10^{*}$ (t-stat in parentheses)

Table 7: Average return, standard deviation and Sharpe ratio

	Average return R ([a]Significant differences from from expected Sharpe ratio of zero indicated)	Average standard deviation σ ([a]Significant differences from equilibrium prediction of .428 indicated)	Sharpe ratio R/σ ([a]Significant differences from expected Sharpe ratio of zero are indicated)
SA Step Asset Market	.038	.532	.115
SC Step Credit Market	-.013	.576**	-.021
CA Concave Asset Market	.179**	.577	.313**
CC Concave Credit Market	-.011	.480	-.042
Two-tailed two-sample Mann-Whitney test results:[a]			
p-value re treatments SA vs SC	.262	.749	.337
p-value re treatments CA vs CC	.055*	.631	.078*
p-value re SA&CA vs SC&CC	.015**	.817	.024**
p-value re SA&SC vs CA&CC	.184	.356	.184

[a]significant test result p < .01***, p < .05**, p < .10*; the one-sample Wilcoxon signed-ranks test is conducted on the independent cohort average (n = 6); the two-sample Mann-Whitney test is conducted on the independent cohort averages ($n_1 = n_2 = 6$).

Table 8: Regression results on efficiency levels and mispricing of market institutions on concentration of claims

	AvgPay	RD	RAD
Constant	.779***	.022	.140***
	(20.1)	(.710)	(7.84)
HHI	.072	.019	.112*
	(.79)	(.11)	(1.73)
AssetD	-.063	-.384	.028
	(-1.08)	(-1.67)	(.17)
AssetD x HHI	-.800***	2.80***	2.09***
	(-4.43)	(7.76)	(6.48)
#observations	534	534	534
#clusters	24	24	12
R-squared	.352	.132	.252

Significant test result is indicated as follows; $p < .01^{***}$, $p < .05^{**}$, $p < .10^{*}$ (t-stat in parentheses)

Table 9A: Regression results on efficiency levels and mispricing of market institutions on concentration of claims (concave payoff function)

	AvgPay	RD	RAD
Constant	.707***	.048	.167***
	(13.0)	(.50)	(7.63)
HHI	.158	-.147	-.034
	(.96)	(-.57)	(-.25)
AssetD	-.123*	-.846***	-.214*
	(-1.95)	(-5.95)	(-1.97)
AssetD x HHI	-.822***	3.44***	2.47***
	(-4.42)	(6.64)	(7.97)
#observations	270	270	270
#clusters	12	12	6
R-squared	.465	.423	.415

Table 9B: Regression results on efficiency levels and mispricing of market institutions on concentration of claims (binary step payoff function)

	AvgPay	RD	RAD
Constant	.876***	.027	.137***
	(68.8)	(.46)	(5.73)
HHI	-.071	.070	.166**
	(-1.32)	(.37)	(2.43)
AssetD	-.079**	-.057	.193
	(-2.88)	(-.15)	(.65)
AssetD x HHI	-.451***	2.74*	2.03
	(-4.87)	(2.00)	(1.68)
#observations	264	264	264
#clusters	12	12	12
R-squared	.455	.132	.232

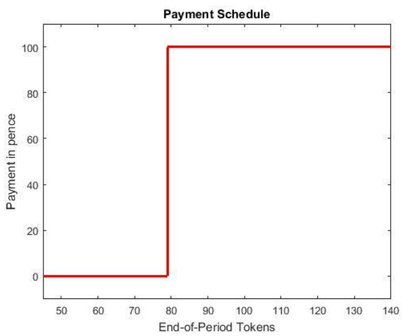
Significant test result is indicated as follows; $p < .01^{***}$, $p < .05^{**}$, $p < .10^{*}$ (t-stat in parentheses)

Table 10 Average *hhi* measures across periods and treatments

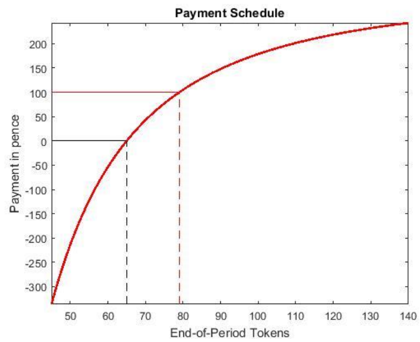
treatment	period 1, 4, 7, …	period 2, 5, 8, ...	period 3, 6, 9, …
Asset market equilibrium	.085	.135	.125
SA	0.149	0.174	0.182
CA	0.174	0.193	0.204
Credit market equilibrium	.194	.139	n/d
SC	0.288	0.261	0.333
CC	0.257	0.262	0.284

Figure 1: The conversion scales from tokens to money

Note: in Step Treatment payoff is £1 at or above 79 tokens and zero otherwise; concave function payoff is £π/100, where $\pi = 309.5734 - 1{,}307{,}948 \times (\#tokens)^{-2}$, yielding £0 at 65 and £1 at 79 tokens.

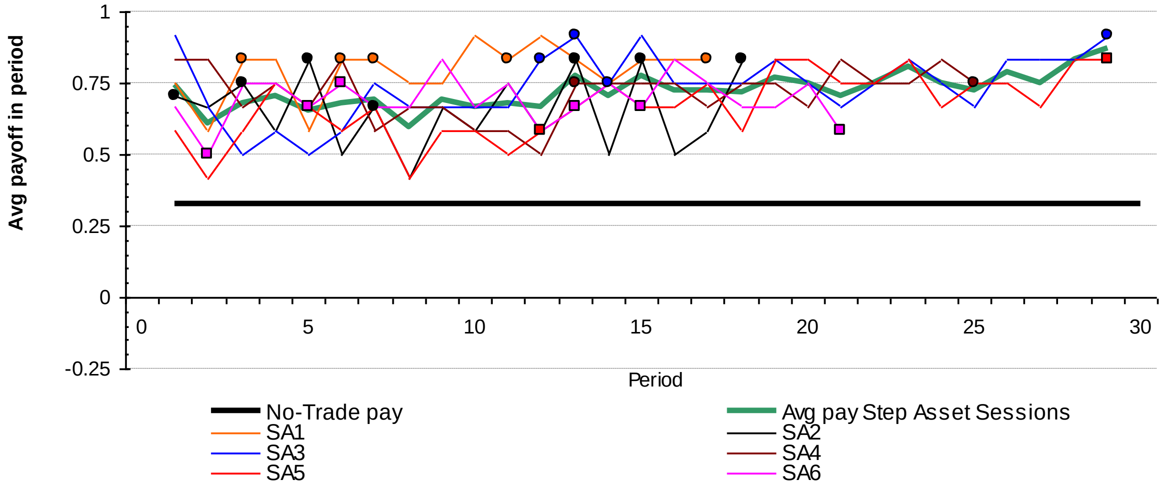


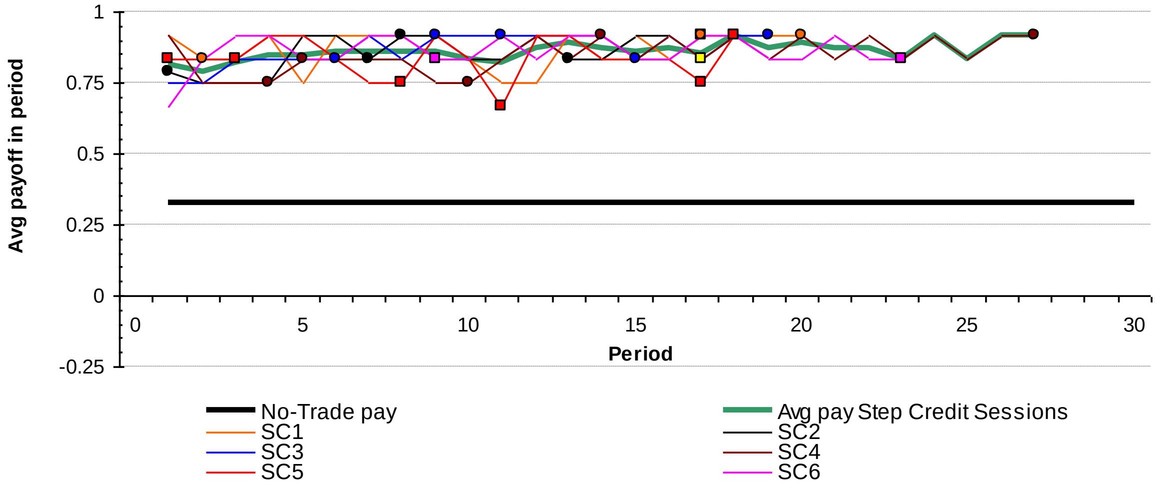
Step Treatment



Concave Treatment

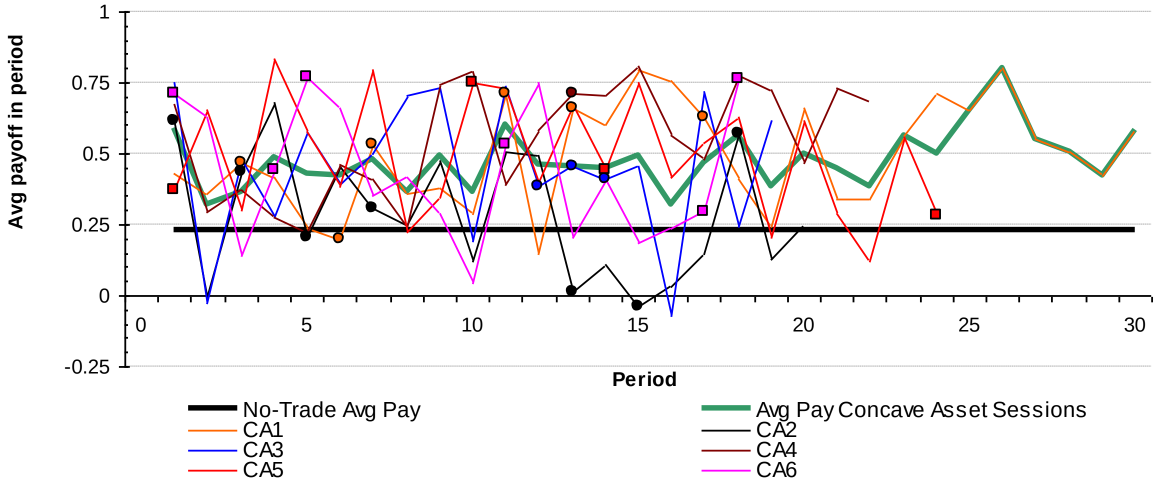
Figures 2: average payoff/consumption with step function (top: asset market, bottom: credit market)
Note: a filled-in circle indicates the end of a sequence; the efficient payoff is £1





Figures 3: average payoff/consumption with the concave function (top: asset market, bottom: credit market)

Note: a filled-in circle indicates the end of a sequence; the efficient payoff is £1



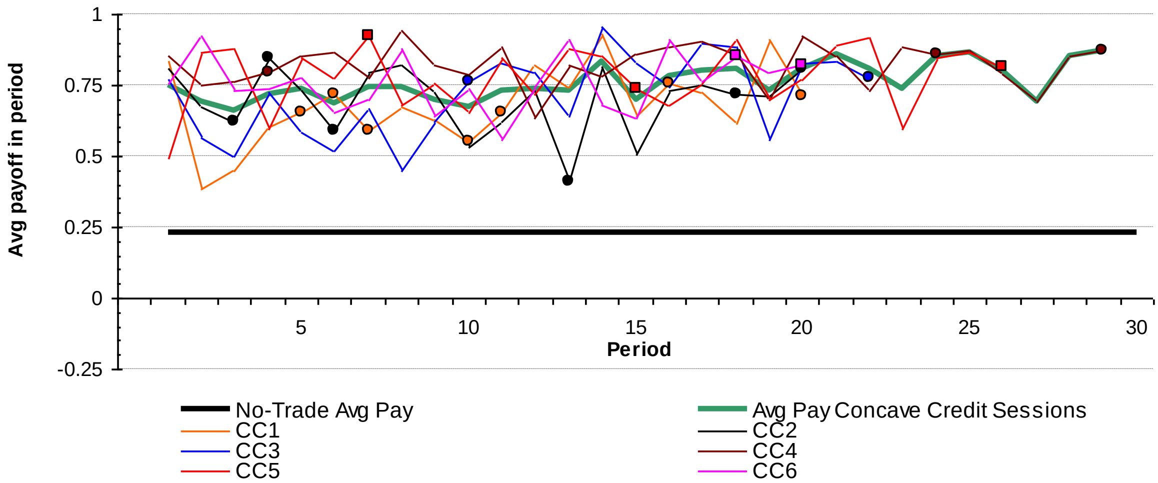
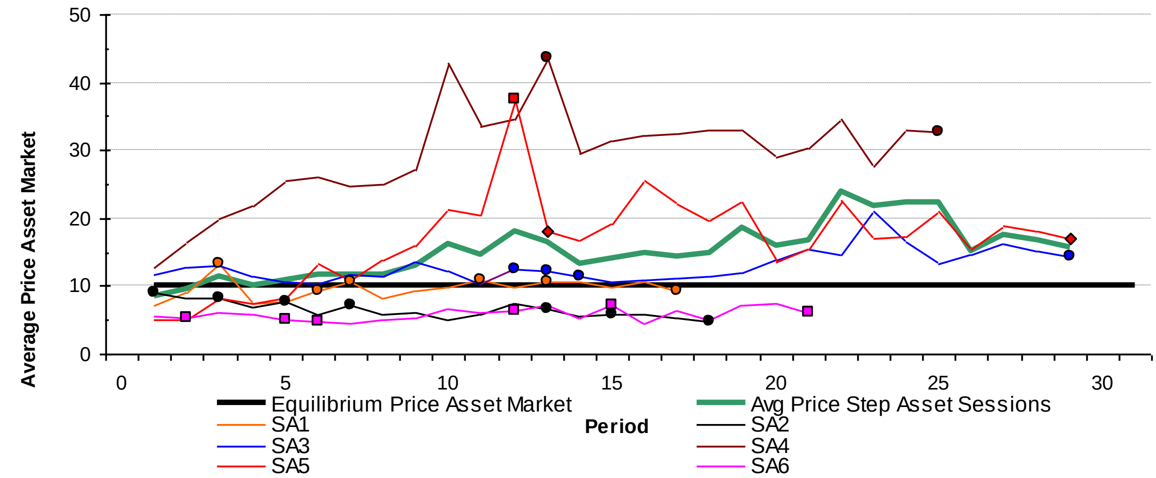


Figure 4: average prices with the step function (top: asset market, bottom: credit market)
Note: a filled-in circle indicates the end of a sequence; scale is 5 times the equilibrium price of 10



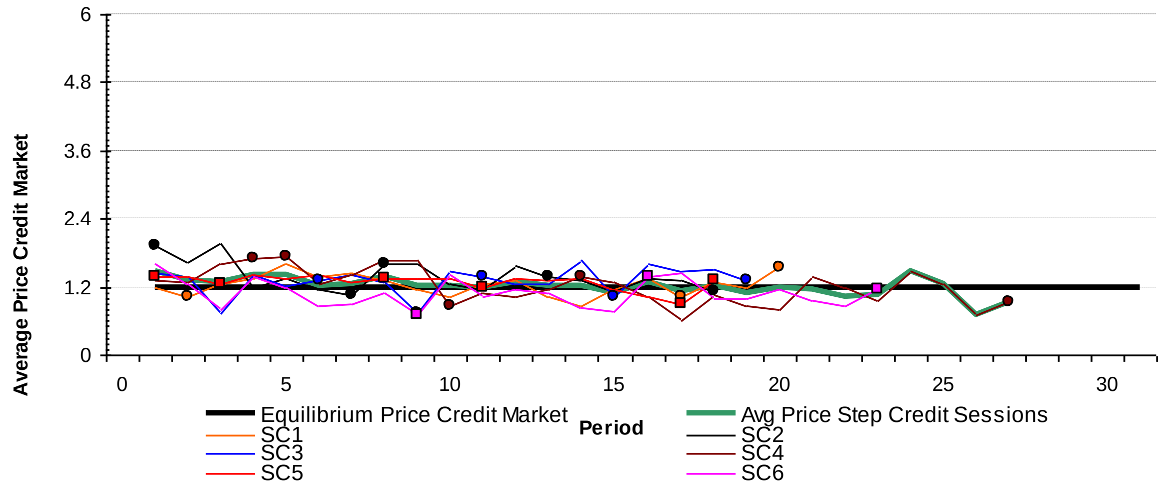
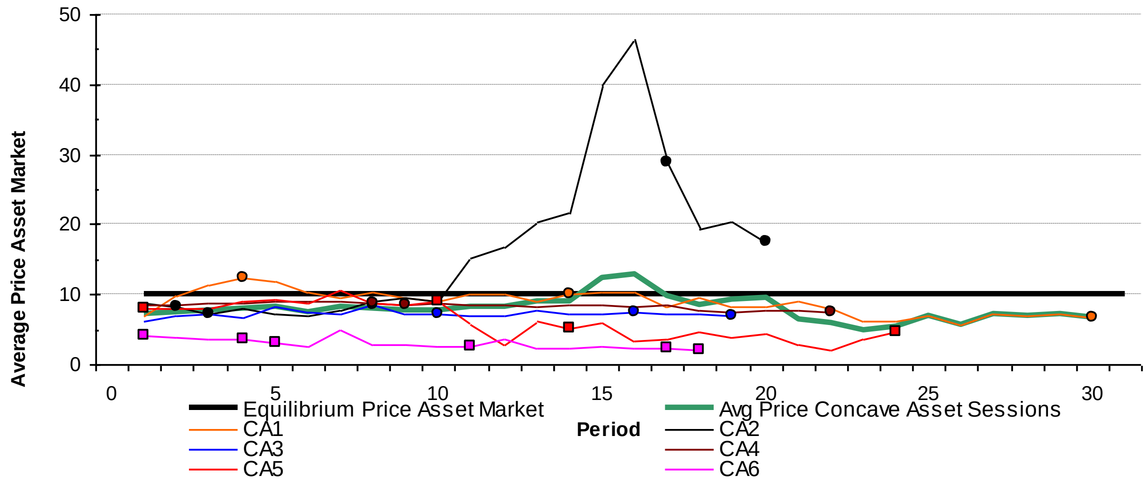


Figure 5: Average Prices with concave function (top: asset market, bottom: credit market)
Note: a filled-in circle indicates the end of a sequence; scale is 5 times the equilibrium price of 1.2



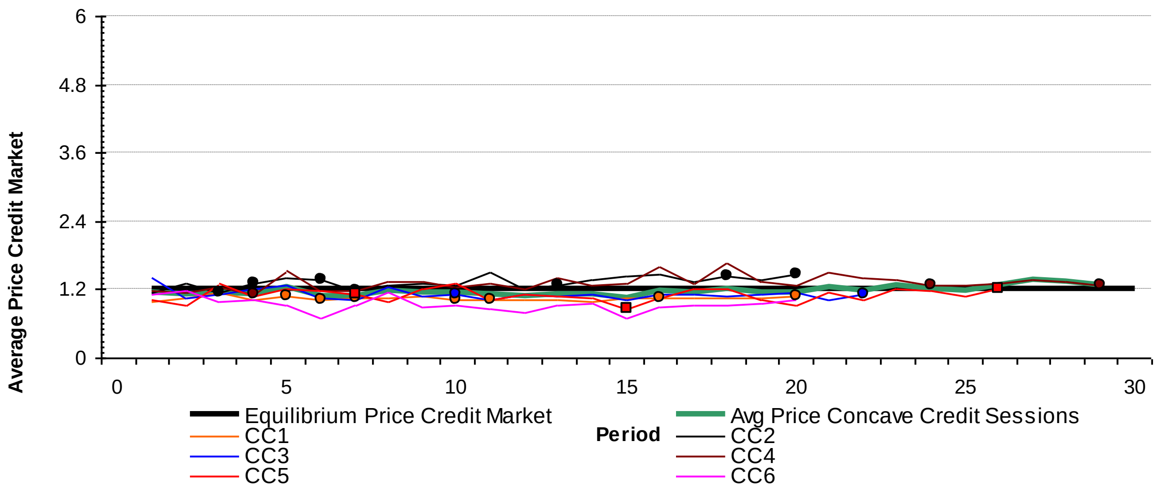


Figure 6: Expected and observed term structure of return, standard deviation and Sharpe ratio
Note: Credit market represents the short-lived claims and asset market the long-lived claims.