A (Bubble-Free) General Equilibrium Approach to Asset Pricing Experiments

Sean Crockett*
Baruch College (CUNY)

John Duffy†
University of Pittsburgh

April 2009

Abstract

We use laboratory experiments to test the modern, consumption-based general equilibrium approach to asset pricing which posits that agents buy and sell assets for the purpose of intertemporally smoothing consumption. These asset pricing models are widely used by macroeconomists and finance researchers but have not yet been subjected to experimental testing. This laboratory approach enables us to induce several fundamental factors which, according to the theory, determine asset prices, such as risk and time preferences, and the process for dividend payments. Preliminary evidence suggests that either intertemporal consumption-smoothing or what can be interpreted as bankruptcy risk in our design (or both) induce stable prices and strongly inhibit the formation of asset price bubbles, a stark departure from most recent asset pricing experiments.

This paper is *very* preliminary and incomplete. **Please do not circulate.**

*Contact: sean.crockett@baruch.cuny.edu
†Contact: jduffy@pitt.edu

1 Introduction

We use laboratory experiments to test the consumption-based general equilibrium approach to asset pricing as pioneered in the work of Stiglitz (1970), Lucas (1978) and Breeden (1979). This approach serves as an important workhorse model in both finance and macroeconomics (or *macrofinance*), as it relates asset prices to individual risk and time preferences, dividends, aggregate disturbances and other fundamental determinants of an asset's value.[1] While this theory has been extensively tested using archival field data, the evidence to date has not been very supportive of the model's predictions. For instance, estimated or calibrated versions of the model generally under-predict the actual premium in the return to equities relative to bonds, the so-called "equity premium puzzle" (Hansen and Singleton (1983), Mehra and Prescott (1985), Kocherlakota (1996)), and the actual volatility of asset prices is typically much greater than the model's predicted volatility based on changes in fundamentals alone – the "excess volatility puzzle" (Shiller (1981), LeRoy and Porter (1981)).

A difficulty with testing the model using field data is that important elements, e.g., individual risk and time preferences, the stochastic dividend process, and other determinants of asset prices, are unknown and have to be calibrated, approximated or estimated in some fashion. An additional difficulty is that the available field data, for example data on aggregate consumption, are measured with error (Wheatley (1988)) or may not approximate well the consumption of asset market participants (Mankiw and Zeldes (1991)). A typical approach is to specify some dividend process and calibrate preferences using micro-level studies that may not be directly relevant to the domain or frequency of data examined by the macro-finance researcher. By contrast, in the laboratory we can accurately measure individual consumption and other data. We can induce players (to some extent) to hold certain risk and time preferences relevant to the time frame of analysis and we can perfectly control other variables affecting fundamentals such as the dividend process, providing us with a better understanding of the environment in which agents are making asset pricing decisions. In addition, in the laboratory we can reliably induce heterogeneity in player types, creating a clear motivation for agents to engage in trade. By contrast, the theoretical literature typically presumes a representative agent and derives equilibrium asset prices such that the volume of trade at those equilibrium prices is zero.

There is a long literature testing asset price formation in the laboratory beginning with the pioneering work of Forsythe, Palfrey and Plott (1982), Plott and Sunder (1982) and Friedman, Harrison and Salmon (1984). This early literature can be viewed as an extension of Smith's (1962) experimental double auction market design for a single, one-period (nonstorable) good to the domain of more durable (2- or 3-period lived) assets yielding stochastic dividend payments. Subjects were predicted to be either buyers or sellers of the asset according to the private dividend value they obtained from holding the asset, which differed in each period. A general finding from this literature is that market prices effectively aggregated private information about asymmetric valuations (dividends) and tended to converge toward rational expectations predictions.

In later, influential work by Smith, Suchanek, and Williams (SSW) (1988), a simple i.i.d. four-state dividend process was made common for all asset owners and endowments were equalized in expected value. There was a known finite number of periods, so the fundamental value of the asset declined at a constant rate over time; there was no apparent reason for subjects to engage in trade at all. Nevertheless, SSW reported that substantial trade in the asset did indeed occur, with prices starting out below the fundamental value, then rapidly soaring above the fundamental value for a sustained duration of time before collapsing near the end of the experiment. The "bubble-crash" pattern found using the SSW design has been replicated by many authors under a variety of different treatment conditions, and has become the primary focus of the large and growing experimental literature on asset price formation (key papers include Porter and Smith

[1] See, e.g., Lengwiler (2004) for a survey.

(1995), Lei, Noussair and Plott (2001), Dufwenberg, Lindqvist and Moore (2005) and Haruvy, Lahav and Noussair (2007); for a review of the literature, see chapters 29 and 30 in Plott and Smith (2008)).[2] Despite many treatment variations (e.g., incorporating short sales or futures markets, computing expected values for subjects, implementing a constant dividend, inserting "insiders" with previous experience in bubbles experiments, using professional traders in place of students as subjects), the only reliable means of eliminating the bubble-crash pattern in the SSW environment has been to replicate the market with the same group of subjects several times.

This paper moves experimental research on asset pricing into a new domain, while building on the many insights and experimental designs found in the existing experimental literature. In particular, we use laboratory methods to test the modern general equilibrium approach to asset pricing used by theoretical and empirical macroeconomic and finance researchers. Consumption-based general equilibrium asset pricing models differ in important ways from the experimental asset pricing environments that have been studied to date. First, the motivation for asset trade is not (as in the early experimental literature) because an asset's dividends are worth more to certain individuals at certain dates in time, but rather because the asset can be used as a means of intertemporally smoothing an agent's consumption profile, which may be subject to exogenous fluctuations over time. While the asset itself may have a stochastic dividend process, the typical assumption in the consumption-based asset pricing literature is that this dividend process is *common* to all owners of the asset, and not different for different agent types. Second, while in the SSW class of experiments the dividend process *is* common to all agents, there is no induced economic incentive for subjects to engage in trade of the asset; trade occurs either because of differences in *indigenous* (home-grown) risk attitudes, or because expectations differ across subjects, or possibly because subjects are bored or would like to please the experimenter. We combine a common dividend process with an induced economic incentive for exchange, standard features in the macrofinance literature.

Third, experimental asset pricing markets typically endow agents with a large number, z, of experimental currency units ("francs") prior to the start of a sequence of trading periods. When the sequence of trading periods is over, the experimenter subtracts z from each subject's end-of-session franc balance and converts the remaining francs into cash at a fixed exchange rate, which comprises the subject's payment for the session. This initial "lump-of-money design," however, is at odds with the sequence-of-budget-constraints faced by agents in equilibrium asset pricing models; in the latter, agents may have some income available to them in every period together with dividends from assets and possibly net borrowings; these monetary resources are typically endogenously determined by decisions in prior periods, though initial conditions must be specified, of course. Importantly, this endogenous sequence of budget constraints may constrain the amount of assets that can be purchased in any given period relative to the SSW design. Together with the absence of a motive for trade, we believe the large initial lump-of-money given to subjects may contribute to the bubbling up of asset prices that is observed in experiments using the SSW design.

Finally, the experimental asset pricing literature seldom takes into account subjects' risk or time preferences. Experimental asset pricing experiments typically have known finite horizons and do not make efforts to either control or evaluate subjects' differing attitudes towards risk (the experimental CAPM literature referenced in footnote 2 is an exception to this characterization). By contrast, macrofinance asset pricing models typically involve infinite planning horizons together with specifications for agents' utility and/or production technologies. In these models, asset prices are functions of deep parameters characterizing time/risk

[2] There is also a recent experimental literature testing capital-asset pricing models (CAPM), e.g., Bossaerts and Plott (2002), Asparouhova, Bossaerts, and Plott (2003), Bossaerts, Plott and Zame (2007). This class of general equilibrium asset pricing models differs from macrofinance models primarily because the assets are short-lived, whereas the assets in our experiment pay a dividend in each period but also serve as a store of value from one period to the next.

preferences and technology. Therefore, it is of interest to attempt to induce and vary such parameters to examine the extent to which they actually impact asset pricing.

There is some prior experimental work on asset pricing that is closely related to our proposal. Camerer and Weigelt (1993) examine an experimental asset market where the motivation for trade was, as in the earlier experimental literature, dividend values which varied across agents: In any single trading period, 1/3 of subjects earned a high dividend from holding the asset, 1/3 a medium dividend and the remaining 1/3 a low dividend. Dividend values for each subject were private information and rotated in a perfect 3-cycle. Importantly, there was a constant .85 probability the asset would continue to exist and pay dividends in the next trading period, and a .15 probability that the asset would cease to exist. Under the assumption that subjects are risk neutral, Camerer and Weigelt demonstrate that the equilibrium price and shareholdings in this economy are equivalent to those in an infinite horizon version of the economy with constant discount factor .85 and continuation probability of one. Trade in the asset occurred via a double auction market. Their main finding is that asset prices converge slowly and unreliably, typically from rather low initial values up toward the predicted price level, reflecting the discounted value of the asset's future dividend stream. They attribute the convergence they do observe to the decisions of a few speculators who bought up most of the available assets and held onto them until prices were driven up. Our design is similar in that we also implement a constant probability with which assets survive from one period to the next and trade of the asset occurs in a double auction market. But our design differs in that we endow agents with utility functions and cyclic incomes, thus providing them with a motivation to smooth consumption. Further, the dividend process for our asset is common and known to all participants. Perhaps most importantly, our design maps more readily into the modern, consumption-based equilibrium asset pricing framework, a feature we hope will make our experimental findings of interest to a broader audience.

2 A simple equilibrium asset pricing framework

We adopt a heterogeneous agent asset pricing framework based on Lucas's (1978) one-tree model. Time t is discrete, and there are N agents split evenly into two types, $i = 1$ and 2, who participate in an infinite sequence of markets. There is a fixed supply of the single, non-reproducible, and infinitely durable asset (trees), each of which yields some stochastic dividend d_t (quantity of fruit) each period. Dividends are paid in units of the single non-storable consumption good at the beginning of each period. Let s_t^i denote the number of asset shares a type i agent owns at the beginning of period t, and let p_t denote the economy-wide price of the asset. In addition to dividend income, agents receive an endowment of the consumption good y_t^i at the beginning of every period. The agent's initial endowment of shares is denoted s_1^i.

The representative agent of type i seeks to maximize:

$$\max_{\{c_t^i\}_{t=1}^{\infty}} E_1 \sum_{t=1}^{\infty} \beta^{t-1} u^i(c_t^i),$$

subject to

$$c_t^i = y_t^i + d_t s_t^i - p_t \left(s_{t+1}^i - s_t^i \right),$$

$$y_t^i + d_t s_t^i - p_t (s_{t+1}^i - s_t^i) \geq 0,$$

$$s_t^i \geq 0.$$

Here, c_t^i denotes consumption of the single perishable good by agent i in t, $u^i(\cdot)$ is a strictly monotonic, strictly concave, twice differentiable utility function, and $\beta \in (0, 1)$ is the (common) period discount factor. The first constraint is the agent's budget constraint. More generally, we could include more than one type of asset, e.g., a risk-free bond in this budget constraint, but we leave that extension for later. The second inequality is a no-borrowing constraint, which is not binding if the Inada condition applies since we restrict dividends to be strictly positive. The third inequality is a no short-sell constraint. We would eventually like to relax one or both of the latter two constraints, but for now we impose them in the interest of simplicity and convenience.

Substituting the budget constraint for consumption in the objective function, and using asset shares as the control, we can restate the problem as:

$$\max_{\{s_{t+1}^i\}_{t=1}^{\infty}} E_1 \sum_{t=1}^{\infty} \beta^{t-1} u^i(y_t^i + d_t s_t^i - p_t(s_{t+1}^i - s_t^i)).$$

The first order condition for each time $t \geq 1$, suppressing agent superscripts for notational convenience, is:

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

Rearranging we have the asset pricing equation:

$$p_t = E_t \mu_{t+1}(p_{t+1} + d_{t+1}), \tag{1}$$

where $\mu_{t+1} = \beta \frac{u'(c_{t+1})}{u'(c_t)}$, a term that is referred to variously as the stochastic discount factor, the pricing kernel, or the intertemporal marginal rate of substitution. If we assume, for example, that $u(c) = \frac{c^{\gamma}}{1-\gamma}$ (the commonly studied CRRA class), we have $\mu_{t+1} = \beta(c_t/c_{t+1})^{\gamma}$. Notice from equation (1) that the price of the asset depends on 1) individual risk parameters such as γ (provided that consumption is growing over time); 2) the individual's rate of time preference r, which is implicit in the discount factor, i.e., $\beta = 1/(1+r)$; 3) the income process; and 4) the stochastic process for dividends, which is assumed to be known and common to both player types.

3 Experimental design

In our experimental design, units of the single consumption good are referred to as "francs," which also serve as the numeraire for endowment income, asset prices and dividends. Shares of the long-lived asset are simply referred to as "assets". The utility function $u^i(c^i)$ serves as a map from subject i's end-of period franc (consumption) balance to U.S. dollars, and is banked by subjects at the end of each trading period; francs are not storable. In all sessions of the experiment we restrict the aggregate endowment of francs and assets to be constant across periods.[3] We also set the dividend equal to a constant value, that is, $d_t = \bar{d}$ for all t, so that a constant steady state equilibrium price exists.[4] Under the constant dividend assumption, applying some algebra to equation (1) yields:

$$p^* = \frac{\bar{d}}{\frac{u'(c_t)}{\beta u'(c_{t+1})} - 1}. \tag{2}$$

This equation applies to all agents, so if one agent experiences consumption growth or decay they all must do so in order to arrive at the same price. But since the aggregate endowment is constant there can be no

[3]The absence of income growth rules out the possibility of "rational bubbles."

[4]If the dividend is stochastic it is straightforward to show that a steady state equilibrium price does not exist, but rather the price will depend (at a minimum) upon the current dividend. See Mehra and Prescott (1985) for a derivation of equilibrium pricing in the representative agent version of this model with a finite-state Markovian dividend process. We felt it was appropriate to begin with the simpler constant dividend framework since our primary motivation was to induce an economic incentive for exchange in a standard macrofinance setting. We note Porter and Smith (1995) show that implementing constant dividends in the SSW design does not reduce the incidence or magnitude of price bubbles.

growth or decay in consumption for all individuals in equilibrium because preferences are strictly monotonic. Thus it must be the case that in a steady state equilibrium each agent perfectly smoothes his consumption, $c_t = c_{t+1}$, so the equilibrium price simplifies to the standard *fundamental price* equation:

$$p^* = \frac{\beta}{1-\beta}\bar{d}. \tag{3}$$

3.1 Inducing a reason to trade

In implementing this single asset pricing model we have to address several methodological issues. Perhaps the most important of these is how to motivate trade in the asset. Equilibrium asset pricing models typically assume a representative agent so that in equilibrium the pricing formulas are associated with trade volumes of zero. Our solution to this problem is (as hinted in the prior section) to introduce agents of two types $i = 1,2$. Agent types differ in three respects: 1) their initial asset holdings, s_1^i; 2) their endowment profiles, $\{y_t^i\}$; and 3) the specifications of their utility functions, $u^i(c)$. Specifically, in all of our experimental sessions we adopted the following design for the two types:

Type	No. Subjects	s_1^i	$\{y_t^i\} =$	$u^i(c) =$
1	6	1	110 if t is odd, 44 if t is even	$\delta^1 + \alpha^1 c^{\phi^1}$
2	6	4	24 if t is odd, 90 if t is even	$\delta^2 + \alpha^2 c^{\phi^2}$

Here δ^i, α^i and ϕ^i are known preference parameters. Notice that the franc endowment for each type follows a perfect two-cycle according to whether the trading period t is odd- or even-numbered. This information was presented privately to each subject at the beginning of the experiment. The 12 subjects were not informed of the number or distribution of induced types, but were told that the aggregate endowment of francs and shares would remain constant across all periods. The utility function u^i for each type provides the conversion between end of trading period consumption (francs), represented by c, and dollars, represented by u. Utility parameters in all treatments were chosen so that in equilibrium each subject earned \$1 per period. The utility function was presented to subjects as a table converting their end–of–period franc balance into dollars, and it was also represented graphically. By inducing agents to hold certain utility functions, we exert some (admittedly imperfect) control over individual preferences, and provide a rationale for trade in the asset.

In our baseline treatment we set $\phi^i < 1$ and $\alpha^i\phi^i > 0$.[5] Given our two-cycle income process, it is straightforward to show that steady state shareholdings must also follow a two-cycle between the initial share endowment, $s_1 = s_{odd}$, and

$$s_{even} = s_{odd} + \frac{y_{odd} - y_{even}}{\bar{d} + 2p}. \tag{4}$$

Notice that in equilibrium subjects buy shares during high income periods and sell shares during low income periods. For example, when $\bar{d} = 2$, the equilibrium prediction ($p = p^* = 10$) calls for type 1 agents to hold 1 share in odd periods and 4 shares in even periods, and for type 2 agents to hold 4 shares in odd periods and 1 share in even periods. When $\bar{d} = 3$, in equilibrium ($p = p^* = 15$) type 1 subjects should cycle between 1 and 3 shares, while type 2 agents should cycle between 4 and 2 shares. In autarky (no asset trade) each subject earned \$1 every two periods, so the incentive to smooth consumption was reasonable strong.

[5]Specifically, $\phi^1 = -1.195$, $\alpha^1 = -311.34$, $\delta^1 = 2.6074$, $\phi^2 = -1.3888$, $\alpha^2 = -327.81$, and $\delta^2 = 2.0627$.

Our primary variation on the baseline treatment was to set $\phi^i = 1$ for both agent types so there was no longer an incentive to smooth consumption.[6] Our aim here was to consider an environment that facilitates comparison with the SSW framework and isolates the impact of the induced incentive for trade on observed prices. In SSW's design, subjects' payoffs were linear in francs and all subjects began a sequence of trading periods with a distribution of francs and assets that were equal in expected value; thus risk neutral subjects had no induced motivation to engage in any asset trade. Nevertheless, trade volume was substantial, with asset prices typically rising rapidly above the implied fundamental trading price before crashing near the known end of each session. We hypothesized that in our linear utility environment we might also observe asset trade at prices greater than the asset's fundamental price, in line with SSW's bubble findings.

To derive the equilibrium price in the linear utility treatment (since the first-order conditions no longer apply), suppose there exists a steady state equilibrium price $\hat{p}$. Substituting each period's budget constraint we can re-write $U = \sum_{t=1}^{\infty} \beta^{t-1} u(c_t)$ as

$$U = \sum_{t=1}^{\infty} \beta^{t-1} y_t + (d + \hat{p}) s_1 + \sum_{t=2}^{\infty} \beta^{t-2} \left[\beta d - (1-\beta)\hat{p}\right] s_t. \tag{5}$$

Notice that the first two right-hand side terms in (5) are constant, because they consist entirely of exogenous, deterministic variables. If $\hat{p} = p^*$, the third right-hand term in (5) is equal to zero regardless of future shareholdings, $\{s_t\}_{t=2}^{\infty}$, so clearly this is an equilibrium price where the corresponding individual equilibrium shareholdings are restricted to sum up to the aggregate endowment of shares in each period . If $\hat{p} > p^*$, the third right-hand term is negative, so each agent would like to hold zero shares, but this cannot be an equilibrium since excess demand would be negative. If $\hat{p} < p^*$, this same term is positive, so each agent would like to buy as many shares as his no borrowing constraint would allow in each period, thus resulting in positive excess demand. Thus p^* is the unique steady state equilibrium price in the case of linear utility.

3.2 Inducing time discounting or bankruptcy risk

A second important methodological issue is how to induce time discounting and the stationarity associated with an infinite horizon. Following Camerer and Weigelt (1993), we addressed this issue by converting the infinite horizon economy to one with a stochastic number of periods. Subjects participated in a number of "sequences," with each sequence consisting of a number of trading periods. Each trading period lasted for three minutes during which time units of the asset could be bought and sold by all subjects in a centralized marketplace (more on this below). At the end of each period subjects took turns rolling a six-sided die. If the die roll resulted in a number between 1 and 5 inclusive, the current sequence continued with another three minute trading period. Each individual's asset position at the end of period t was carried over to the start of period $t+1$, and the common, fixed dividend amount, $\overline{d}$, was paid on each unit carried over. If the die roll came up 6, the sequence of trading periods was declared over and all subjects' assets were declared worthless. Thus, the probability that assets would continue to have value in future trading periods was 5/6 (.833), which was our means of implementing time discounting, i.e., $\beta = 5/6$. We prove below that this indefinite horizon economy has the same steady state price and equilibrium shareholdings as the infinite horizon economy, provided subjects are risk neutral (we also consider consequences for prices and allocations when they are not).

The fact that the asset may become worthless at the conclusion of any period has a natural interpretation as *bankruptcy risk*, where the firm issuing the security is assumed to become completely worthless with constant probability. This type of risk is *not* present in any existing experimental asset pricing models

[6] In this treatment, $\alpha^1 = 0.0122$, $\alpha^2 = 0.0161$, and $\delta 1 = \delta^2 = 0$.

aside from Camerer and Weigelt's study. For instance, in SSW the main risk that agents face is *price risk* – uncertainty about the future price of assets– as it is known that assets are perfectly durable and will continue to pay a stochastic dividend (with known support) for T periods, after which time all assets will cease to have value.[7] However, participants in financial markets face both price risk *and* bankruptcy risk, as recent events have made quite clear (these two risks are related, obviously, when bankruptcy is a possibility). It is therefore of interest to examine asset pricing in environments where both types of risk are present; it is possible that bankruptcy risk (if sufficiently salient) can interact with indigenous subject risk aversion to inhibit the formation of asset price bubbles.

To give subjects experience with the possibility that their assets could become worthless and in the process induce the stationarity associated with an infinite horizon, our experimental sessions were set up so that there would likely be several sequences of trading periods. We recruited subjects for a three hour block of time, and informed them they would participate in one or more sequences consisting of indefinite numbers of trading periods for at least one hour after the instructions were completed. Following one hour of play (during which time one or more sequences were typically completed), subjects were informed that the sequence they were then currently playing would be the last one played, i.e., the next time a 6 was rolled the current sequence and session would be over. This design ensured that we would get a reasonable number of trading periods, while at the same time limiting the possibility that the session would not finish within the 3-hour time-frame for which subjects had been recruited (the expected mean/median number of trading periods per sequence was 6/4). Indeed, in our pilot sessions, we never failed to complete the final sequence within three hours.[8]

Summarizing, the innovation of our design is to provide a consumption-smoothing motivation for agents to engage in trade of the asset, while respecting the sequence of budget constraints that agents in macro-finance models typically face, and inducing the stationarity associated with an infinite horizon by having a constant probability of termination to a sequence of trading periods, a design feature that can be interpreted as inducing either time discounting or bankruptcy risk. These innovations move the asset pricing framework we study much closer to that of the models used in the macro-finance literature. The linear treatment facilitates the comparison of the "conventional" macrofinance treatment with the well-studied SSW framework.

3.3 The trading mechanism

A third methodological issue is how to implement asset trading. Equilibrium models simply combine first order conditions for portfolio choices with market clearing conditions to obtain equilibrium prices, but do not specify the actual mechanism by which prices are determined and assets are exchanged. Here we adopt the double auction mechanism, as it is well known to reliably converge to competitive equilibrium outcomes in a wide range of experimental markets. We use the double auction found in Fischbacher's (2007) z-Tree software. Specifically, prior to the start of each three minute trading period t, subjects were informed of their initial asset position s_t^i, and the number of francs they have available for trade in period t, equal to $y_t^i + s_t^i \bar{d}$. The dividend amount paid per unit of the asset held at the start of a period, $\bar{d}$, was made common knowledge (via the experimental instructions) as was the discount factor, β. After all subjects clicked a

[7]There is also some dividend risk but it is relatively small given the number of draws relative to states. And as noted before, Porter and Smith (1995) show that a SSW-style asset market with a constant dividend process exhibits the same bubble-crash pattern as observed in the stochastic dividend design.

[8]In the event that we did not complete the final sequence by the three hour limit, we informed subjects at the beginning of the experiment we would bring all of them back to the laboratory as quickly as possible to complete the final sequence. Subjects would be paid for all sequences that had ended in the current session, but would be paid for the continuation sequence only when it had been completed. Their financial stake in that final sequence would be derived from at least 25 periods of play, which makes such an event very unlikely (about %1) but quite a compelling motivator to get subjects back to the lab.

button indicating that they understood their beginning of period asset and franc positions, a three minute trading period was begun. Subjects could post buy or sell orders for one unit of the asset at a time, though they were instructed that they could sell as many assets as they had available, or buy as many assets as they wished so long as they had sufficient francs available. During a trading period, standard double auction improvement rules were in effect: buy offers had to improve on (exceed) existing buy offers and sell offers had to improve on (undercut) existing sell offers before they were allowed to appear in the order book visible to all subjects. Subjects could also agree to sell at any posted buy price or to buy at any posted sell price at any time during the period by clicking a button. In that case, a transaction was declared and the transaction price was shown to all participants. The agreed upon transaction price in francs was paid from the buyer to the seller and one unit of the asset was transferred from the seller to the buyer. The order book was cleared, but subjects could (and did) immediately begin reposting buy and sell orders. A history of all transaction prices in the trading period was always present on all subjects' screens, which also provided information on asset trade volume. In addition to this information, each subject's franc and asset balances were adjusted in real time in response to any transactions.

3.4 Subjects, payments and timing

Subjects were recruited from the undergraduate population of the University of Pittsburgh. No subject participated in more than one session. At the beginning of each session, the 12 subjects were randomly assigned a role as either a type 1 or type 2 agent, such that there were 6 of each type. Subjects remained in the same role for the duration of the session. Subjects were seated at computer workstations and were given written instructions that were also read aloud prior to the start of play in an effort to make the instructions public knowledge. As part of the instructions, subjects were required to complete two quizzes to test their comprehension of their induced utility function, the asset market trading rules and other features of the environment; the session did not proceed until all subjects had answered these quiz questions correctly. Copies of the instructions and quizzes are available at `http://www.pitt.edu/ jduffy/assetpricing`. Subjects were recruited for a three hour session, but a typical session ended after two hours. Subjects earned their payoffs from every period of every sequence played in the session. Average payoffs in our four pilot sessions were $21.22 per subject, including a $5 show-up payment.

At the end of each period t, subject i's end-of-period franc balance was declared his consumption level, c_t^i, for that period; the dollar amount of this consumption holding, $u^i(c_t^i)$, accrued to his cumulative cash earnings (from all prior trading periods), which were paid at the completion of the session.

The timing of events in our experimental design is summarized below.

t					$t+1$
	dividends paid: francs=$s_t^i\bar{d}+y_t^i$ assets=s_t^i	3-minute trading period using a double auction to trade assets and francs	consumption takes place $c_t^i = s_t^i\bar{d}+y_t^i + \sum_{k_t^i=1}^{K_t^i} p_{t,k_t^i}\left(s_{t,k_t^i-1}^i - s_{t,k_t^i}^i\right)$	die role: continue to $t+1$ w.p. 5/6, else end.	

In this timeline, K_t^i is the number of transactions completed by i in period t, p_{t,k_t^i} is the price governing the kth transaction for i in t, and $s_{t,k_t^i}^i$ is the number of shares held by i after his kth transaction in period t. Thus $s_{t,0}^i = s_t^i$ and $s_{t,K_t^i}^i = s_{t+1}^i$. Of course, this summation does not exist if i did not transact in period t; in this "autarkic" case, $c_t^i = s_t^i\bar{d}+y_t^i$. In equilibrium, sale and purchase prices are predicted to be identical over time and across subjects, but under the double auction mechanism they can differ within and across periods and subjects.

4 Preliminary experimental findings

Thus far we have conducted six experimental sessions. Each session involved 12 subjects, (six type 1 and six type 2) with no prior experience in our experimental design (72 subjects total). The treatments used in these six sessions are summarized in the table below.

Session	$\bar{d}$	$u(c)$	
1	2	concave	
2	3	concave	
3	2	linear	
4	3	linear	
5	2	linear	
6	2	concave	

Based on the discussion above, we report on several findings of interest. We caution that we do not yet have enough data to test for the statistical significance of the different patterns of behavior that we observe; rather these findings are suggestive of what we might expect to observe following several more sessions of each treatment.

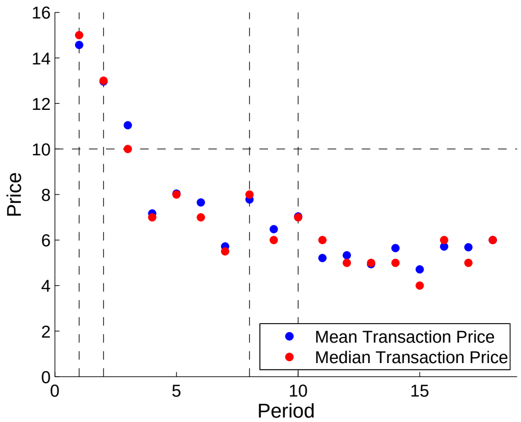
Finding 1 *In the concave utility treatment ($\phi^i < 1$), observed transaction prices stabilize at a price below $p^* = \frac{\beta}{(1-\beta)}\bar{d}$.*

Figure 1 shows mean and median prices for the three sessions where the concave utility function was induced. In these graphs, dashed vertical lines denote the first period of each indefinite trading sequence. Dashed horizontal lines indicate the predicted equilibrium price, which is 10 in the $\bar{d} = 2$ treatment and 15 in the $\bar{d} = 3$ treatment. We observe that the average median transaction price during the final 5 periods is 5.2 and 9.2 in sessions 1 and 6 (where $\bar{d} = 2$), and around 7.5 in session 2 ($\bar{d} = 3$), which is 52%, 92%, and 50% of the predicted price levels, respectively. Notice that after some initial experimentation, there is not much variation in transaction prices over time and no evidence of any pronounced bubble-crash pattern despite our use of inexperienced subjects.

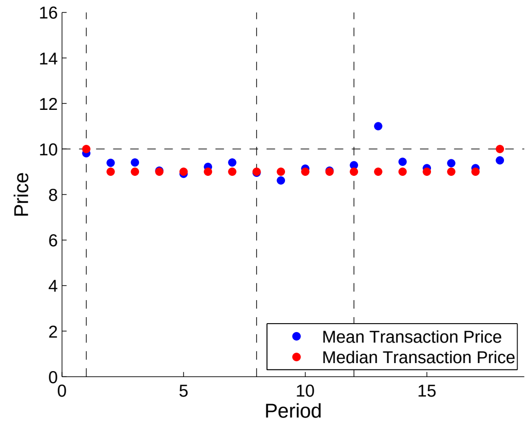
We plan to run at least three more sessions of this treatment to determine whether the observed convergence in prices to levels below equilibrium is a robust finding. In the preliminary analysis of indigenous (homegrown) risk preferences in the next section, we will demonstrate that if subjects' risk preferences are drawn from a typical distribution reported in the literature, prices should typically begin below the fundamental price. However, indigenous risk-aversion does not explain why prices remain so low throughout two of the sessions; prices should be rising over time but they do not. Our conjecture is that many subjects are exhibiting risk-aversion that is not conditional on cumulative earnings in the experiment. We will also show that in session 6 more subjects behave risk-neutrally than in the other two sessions, presumably leading to substantially higher prices.

Finding 2 *In the concave utility treatment, there is strong evidence that subjects are using the asset to intertemporally smooth their consumption.*

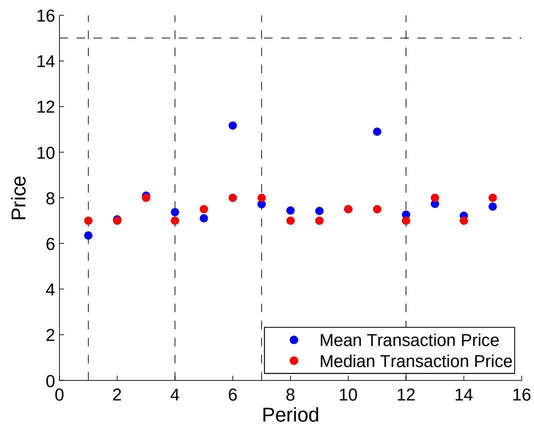
Figure 2 shows the per capita shareholdings of type 1 (odd) subjects by period (the per capita shareholdings of type 2 (even) subjects is 5 minus the per capita type 1 shares). Again, dashed vertical lines denote



(a) Session 1: $\bar{d} = 2$



(b) Session 6: $\bar{d} = 2$



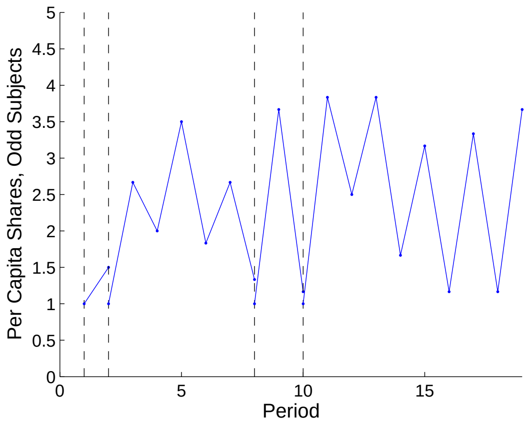
(c) Session 2: $\bar{d} = 3$

Figure 1: Price in Concave Utility Sessions

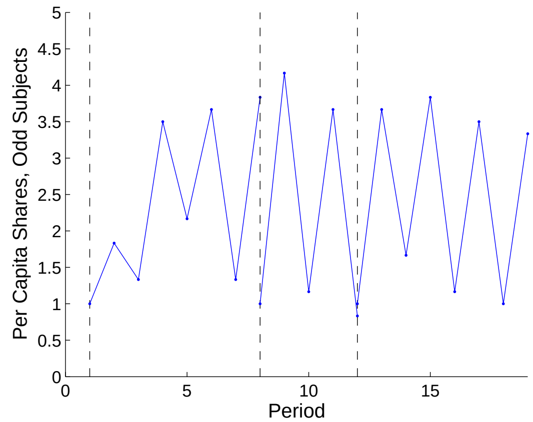
the first period of a sequence.[9] Recall that equilibrium shareholdings should follow a perfect two-cycle, increasing in periods when subjects have large franc endowments and decreasing in periods when subjects have small franc endowments. As Figure 2 indicates, a two-cycle pattern (at least in sign) is exactly what occurred in each and every period on a per capita basis.[10] Recall that type 1 shareholdings should alternate between 1 and 4 units per period in the $\bar{d} = 2$ treatment and between 1 and 3 units per period in the $\bar{d} = 3$ treatment under the assumption of indigenous risk neutrality. While the observed per capita shareholdings depart somewhat from these predictions, so too, do prices, and together these departures can be rationalized under a plausible distribution for subject risk preferences. In fact, in session 6, where prices were nearly equal to the fundamental price throughout, the per capita shareholdings were almost exactly equal to equilibrium shareholdings. To date, the limited experimental evidence on whether subjects can engage in consumption-smoothing has not been encouraging (see, e.g., Noussair and Matheny (2000)); we appear to have developed a design where consumption-smoothing comes rather naturally to most subjects. It should be noted there

[9]Since each subject begins period t with s_t^i and finishes the period with s_{t+1}^i, all vertical lines but the first also correspond to shares that were bought in the final period of the previous sequence but which expired without paying a dividend.

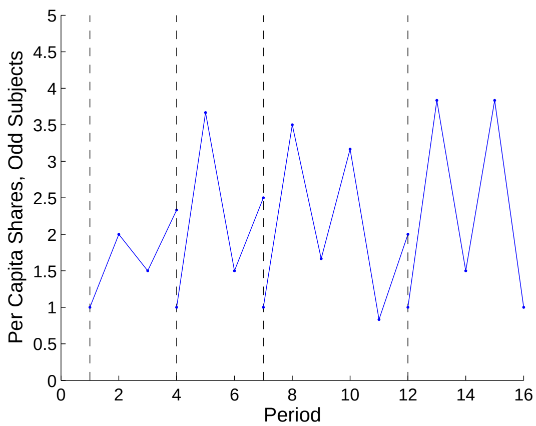
[10]In these figures, the period numbers shown are aggregated over all sequences played. The actual period number of each individual sequence starts with period 1, which is indicated by the dashed vertical lines.



(a) Session 1: $\bar{d} = 2$



(b) Session 6:$\bar{d} = 2$



(c) Session 2: $\bar{d} = 3$

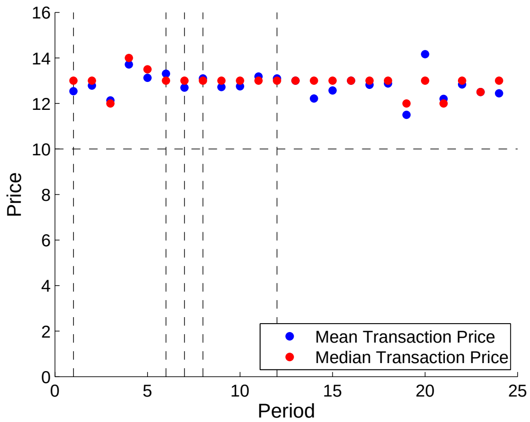
Figure 2: Shares in Concave Utility Sessions

is no consumption smoothing at the aggregate level in two of the three linear sessions, while in the third (session 3) there is some consumption-smoothing in a majority of periods but at only about half of a share per capita.

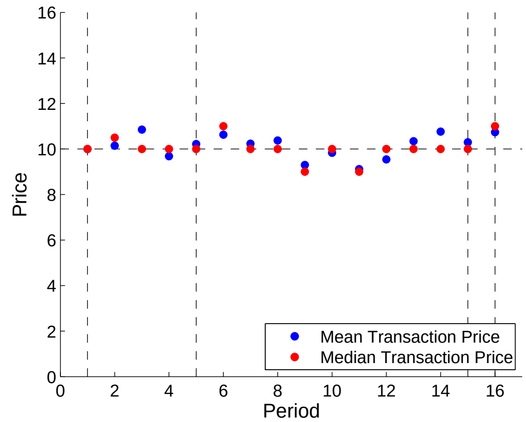
Finding 3 *In the linear utility case ($\phi^i = 1$), trade in the asset does occur. Observed transaction prices are higher than in the corresponding concave case (same value of $\bar{d}$), but we do not observe price bubbles and crashes. Indeed, prices are close to the predicted fundamental price, p^*.*

Figure 3 shows mean and median transaction prices for the linear sessions. In session 3, the average median price during the final five periods was 12.7, 27% above the fundamental price. In session 5, the average median price during the final five periods was 10.2, 2% above the fundamental price. And in session 4, the average median price during the final five periods was 11.7, 22% below the fundamental price (in this session prices continued to climb upward throughout, ending at a price of 13).

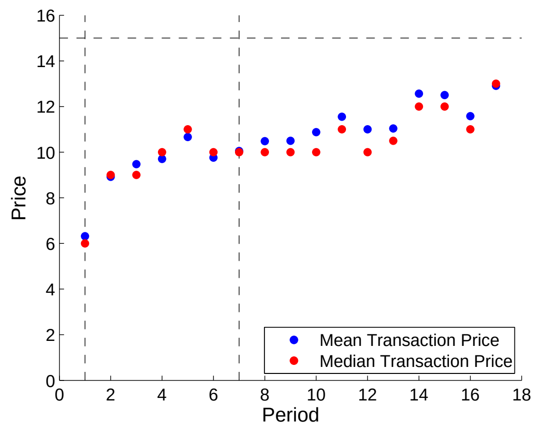
In the following section we plan to formally derive how a reasonable distribution of indigenous risk preferences can support this result, but here is the intuition. Suppose there are at least two risk-neutral



(a) Session 3: $\bar{d} = 2$



(b) Session 5: $\bar{d} = 2$



(c) Session 4: $\bar{d} = 3$

Figure 3: Price for Linear Sessions

subjects per session.[11] In the linear treatments these subjects quickly bid the price up to fundamental value, because at a lower price they demand all shares up to their budget constraints. However, in the concave treatments their desire to smooth consumption inhibits their demand (relative to the linear case) at prices below fundamental value. Risk-averse subjects remain active in the market in the concave treatments because they too wish to smooth consumption, but they would like to buy less in high income periods and sell more in low income periods than risk-neutral subjects. A price below fundamental value is required to keep supply and demand in balance in the concave treatment, provided most subjects are risk-averse, whereas in the linear treatment there is excess demand for any price below fundamental value.

Finding 4 *In the linear utility treatment, there is evidence of hoarding of the asset by just a few subjects.*

In the linear treatment subjects have no induced motivation to consumption smooth and thus no reason to trade at p^* under the assumption of risk neutrality. However, we observe substantial trade in these

[11]Holt and Laury (2002) identify 34% of subjects to be risk-neutral or risk-seeking in their low stakes treatment, and 19% in their high stakes (20x) treatment. Harrison, Lau, Rutstrom, and Sullivan (2005) find 24.2% of participants to be risk-neutral or risk-seeking in a large field study in Denmark. Thus the existing literature implies that the probability at least 2 of 12 subjects in our sessions are not risk-averse is relatively high, in the neighborhood of 85%.

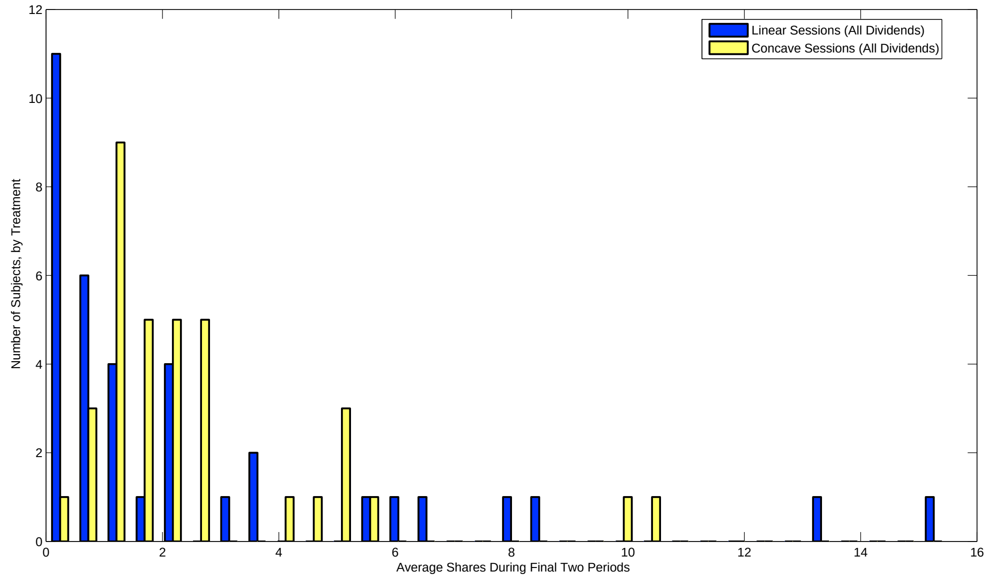


Figure 4: Distribution (by Treatment) of Mean Shareholdings During the Final Two Periods

sessions, with most subjects selling all or nearly all of their shares. Figure 4 displays the distribution of mean individual shareholdings during the final two periods of the final sequence of each session, aggregated by treatment (linear vs. concave). [12] We average across the final two periods to smooth the data from consumption smoothers, as quite a few of the subjects in the concave treatment are cycling between zero and one or two shares. Notice that 17 of 36 subjects across the linear sessions held an average of 0.5 shares or less during the final two periods, compared to only 4 of 36 subjects who held these amounts in the concave sessions. At the other extreme, 6 subjects held an average of 6 shares or more during the final two periods of the linear sessions, versus only 2 subjects in this range in the concave sessions. In the middle of the distribution, more than 80% of the subjects in the concave sessions held an average of 1-5 shares during the final two periods, well more than double the percentage of subjects with shareholdings in this range in the linear sessions.

We now consider hoarding at the session level in the linear treatment. Two subjects in each of the linear sessions hoarded assets. In session 3 the two subjects holding the most shares in the final period held 9 and 7 shares (53%), no one else held more than 4.[13] In session 4 the two subjects holding the most shares in the final period held 17 and 9 shares (87%), no one else held more than 1. And in session 5 the two subjects holding the most shares in the final period held 16 and 6 shares (73%), no one else held more than 2.

Summarizing, we conjecture that the pattern of asset prices and asset positions we observe in our six preliminary sessions can be supported as equilibrium prices under a plausible distribution for indigenous risk preferences, although we should expect to see prices increasing towards the fundamental price over time within sequences of the concave sessions and we do not. Importantly, in our design we do not observe behavior that might be characterized as an asset price bubble, i.e., prices at levels far from fundamentals for

[12] For the purpose of this discussion we consider the final period of the penultimate sequence for session 5, since the final two sequences lasted only one period each.

[13] Here we discuss shares in the final period rather than average shares over the final two periods because subjects generally do not smooth consumption in the linear treatment.

a sustained period of time (except perhaps a mild one in session 3), nor do we observe asset price crashes. We preliminarily conclude that the presence of an induced incentive to trade or the presence of a constant bankruptcy risk (or both) appear to greatly reduce the potential for asset price bubbles.

5 Indigenous risk preferences [Very Preliminary]

Superscripts indexing individual subjects are suppressed for notational convenience. Let $m_t = u(c_t)$ and $M_t = \sum_{s=0}^{t} m_s$ be the sum of dollars a subject has earned through period t of the current sequence, given dollar wealth m_0 brought into the sequence.[14] Let $v(x)$ be a subject's indigenous (homegrown) utility of x dollars, and suppose this function is strictly concave, strictly monotonic, and twice differentiable. Then the subject's expected value of participating through the current sequence is

$$V = \sum_{t=1}^{\infty} \beta^{t-1} (1-\beta) v(M_t) . \tag{6}$$

Using $\langle s_t \rangle_{t=2}^{\infty}$ as the control, the first order conditions with respect to s_{t+1} for $t \geq 1$ can be written as

$$u'(c_t) p_t \sum_{s=t}^{\infty} \beta^{s-t} E_t\{v'(M_s)\} = \sum_{s=t}^{\infty} \beta^{s-t+1} E_t\{v'(M_{s+1}) u'(c_{t+1}) (d + p_{t+1})\} \tag{7}$$

At this point, we assume subjects have myopic expectations with respect to future prices; in particular, each subject expects the price in all future periods to equal the current price with probability one. We will eventually expand this analysis to include a richer family of expectations (e.g., assume price takes a log-normal random walk). Since our preliminary results indicate that prices tend to become quite stable in most sessions, the extreme myopia we posit for the time-being is probably a reasonable first-cut assumption. Thus consider constant price p. Given such a price, the subject's first-order condition reduces to

$$p = \frac{d}{\frac{u'(c_t)}{u'(c_{t+1})} \left(1 + \frac{v'(M_t)}{\sum_{s=t}^{\infty} \beta^{s-t+1} v'(M_{s+1})}\right) - 1} \tag{8}$$

Notice the similarity of (8) to (2). This is not a coincidence; if indigenous risk preferences are linear, the indigenous marginal utility of wealth is constant, and applying a little algebra to (8) produces (2).

5.1 Linear Induced Preferences

Now suppose induced utility is linear, so $\phi = 1$ and $u(c) = \alpha c$ (note $\delta = 0$ in the experiment). Then prices can be constant only if $v'(M_{t+1}) = kv'(M_t)$ for all t, where $k \in (0,1)$ is a constant rate of decay of marginal utility (this condition provides an interior solution, which must be unique by strict concavity). Thus (8) reduces to

$$p = \frac{k\beta}{1-k\beta} \bar{d} \tag{9}$$

Suppose subjects exhibit CRRA preferences of the form $v(m) = \frac{1}{1-\gamma} m^{1-\gamma}$, where $\gamma \in (0,1)$. Then $k = \left(\frac{m_t}{m_{t+1}}\right)^{\gamma}$. Substituting this expression into (9) and doing some algebra, we obtain the condition

$$m_{t+1} = g m_t \tag{10}$$

[14] At this point m_0 is quite general, and may include some combination of show-up fee, cumulative earnings, and even wealth outside of the lab. m_0 may also be reset to zero at the beginning of each sequence. The ultimate choice of initial wealth will be data-driven.

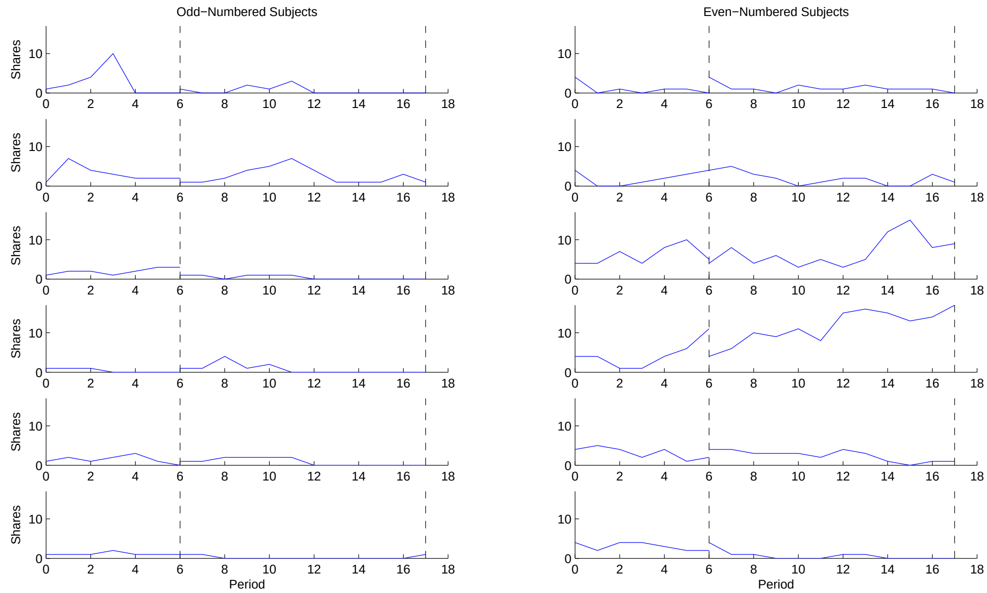


Figure 5: Individual Shareholdings in Session 4 (Linear Induced Utility)

where $g = \left[\frac{(\bar{d}+p)\beta}{p}\right]^{\frac{1}{\gamma}}$ is the optimal growth rate of wealth during the sequence from period 2 forward (note that logarithmic utility implies the same growth rate as (10) with $\gamma = 1$). If $p = p^*$ then $g = 1$, so consumption is zero after the first period at the interior solution. Since we assume subjects cannot borrow against future income, a risk-averse subject facing constant price p^* thus should sell all of his assets in the first period and simply consume his income in subsequent periods (this is also true for $p > p^*$, in which case $g < 1$).

For $p < p^*$ we have $g > 1$, so the subject prefers for his wealth to grow over time at a constant rate. This growth rate is increasing in the risk-aversion of the subject and decreasing in price (that is, g is decreasing in γ and p), so a more risk-averse subject facing higher prices prefers more of his earnings in the sequence up-front. Eventually desired wealth explodes, which makes intuitive sense since the curvature of the subject's utility function becomes approximately linear at "high" levels of consumption; he eventually behaves like a risk-neutral subject once he's accumulated a sufficient amount of wealth. Note that it is not possible for all subjects to behave as risk-averse expected utility maximizers for a constant price, because aggregate income in the experiment is constant in each period.

Let's reconsider session 4 in light of this discussion (in the other two linear sessions prices were greater than or equal to the fundamental price throughout, so risk averse subjects should obviously stay out of the market entirely). From Figure 3(c) we observe that the median transaction price from periods 4 through 13 was between 10 and 11. How should a subject with indigenous CRRA preference parameter $\gamma = 0.5$ (a commonly estimated mean degree of risk aversion) who naively believes prices will be a constant 10.5 forever behave in the first period of new sequence? A type 1 subject with at least \$4.30 of accumulated earnings (recall the show-up fee alone is \$5) should use his entire income to purchase shares in the current period. Since no subjects do this and only a couple of subjects hold more than 2 or 3 shares throughout the session (see Figure 5), let's minimize wealth effects by assuming the subject treats wealth in each sequence independently (so that $m_0 = 0$). This subject should sell his only share of the asset in the first period and

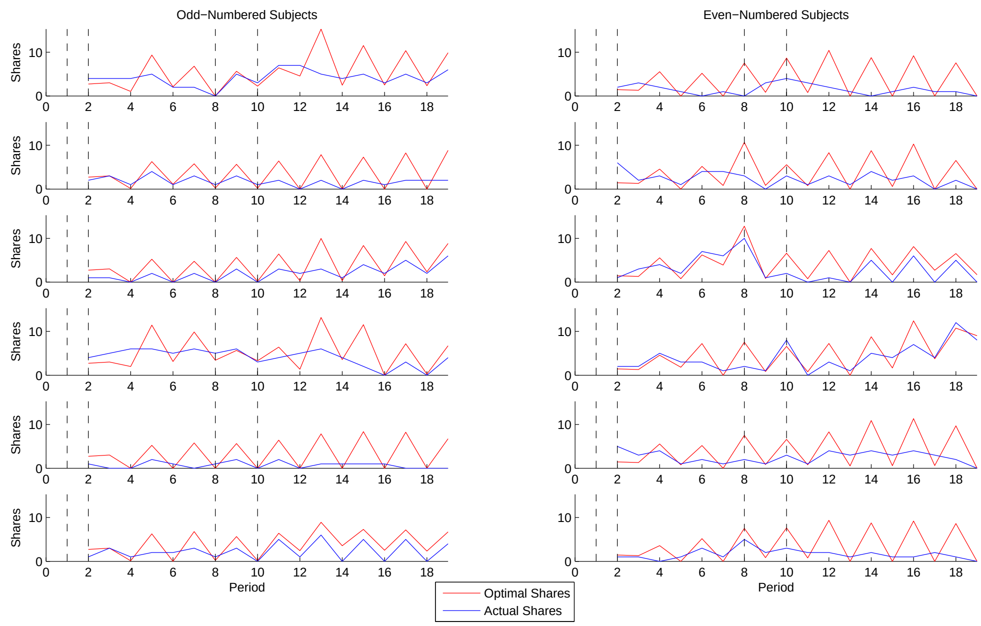


Figure 6: Actual vs. Optimal Shares in Session 1

consume all of his income in the second period, as well. However, in the third period he should purchase 2 shares, in the fourth he should purchase one more, and then beginning in the fifth period his share purchases should explode (buying 7 shares in the fifth period, 2 more in the sixth, 9 in the seventh, and so on). This predicted wealth effect is far more powerful than anything we observe in the session (and would have contributed to a rapid increase in prices).

But now consider the behavior of a risk-averse agent who ignores wealth effects entirely, even within a sequence. Suppose the price is expected to remain a constant 10.5 with probability one and consider the remainder of the sequence as a compound lottery. Then the expected value (in francs) of an asset share that pays dividend $\bar{d} = 3$ per period for CRRA parameter $\gamma = 0.5$ is 10.41. Thus subjects with a typical degree of risk aversion who ignore wealth effects should be nearly indifferent to buying or selling shares at the prices observed from periods 4-13 in session 4. If the subjects expect even a little price uncertainty it is not surprising we observe most of them largely staying out of the market. Also note from Figure 5 that by period 12, when prices begin to track upward, many subjects sell all remaining shares and stay out of the market for the duration of the session.

5.2 Concave Induced Preferences

We begin with a very loose characterization of subject-level data. For the moment we make the simplifying assumption that subjects expect the mean transaction price in the current period will be the price in all future periods with certainty.

Figures 6-8 depict actual period-ending individual shareholdings in each session and the risk-neutral optimal shareholdings conditional on current income, shares, and the constant price assumption. Thus the optimal quantity of shares for subject i in period 3, s_3^i, is the quantity of shares that should be bought by i (if risk-neutral) during period 2 trading given his period 2 shares and income, along with period 2 prices expected to remain constant forever.

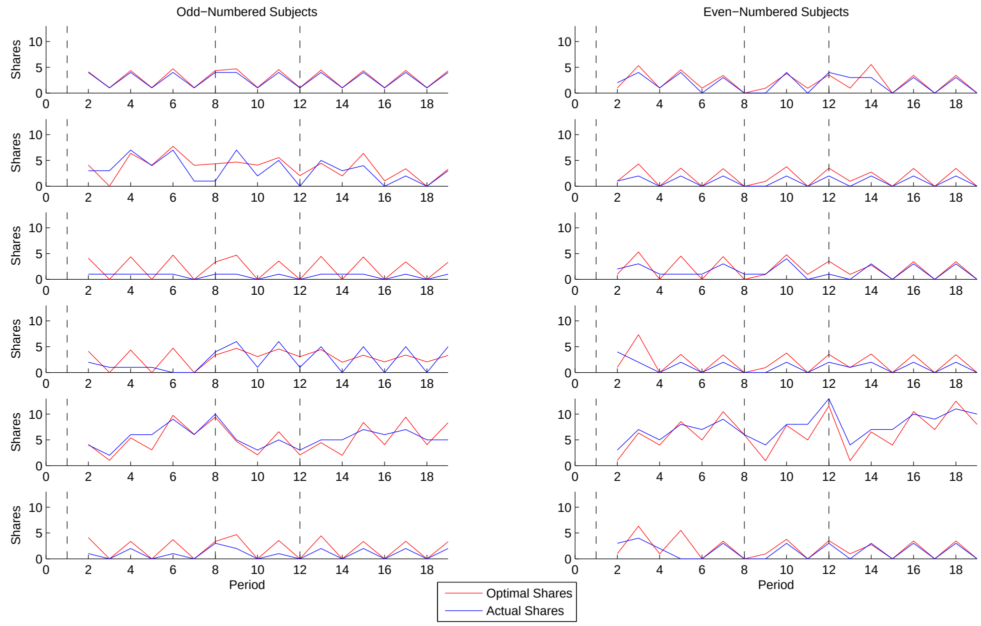


Figure 7: Actual vs. Optimal Shares in Session 6

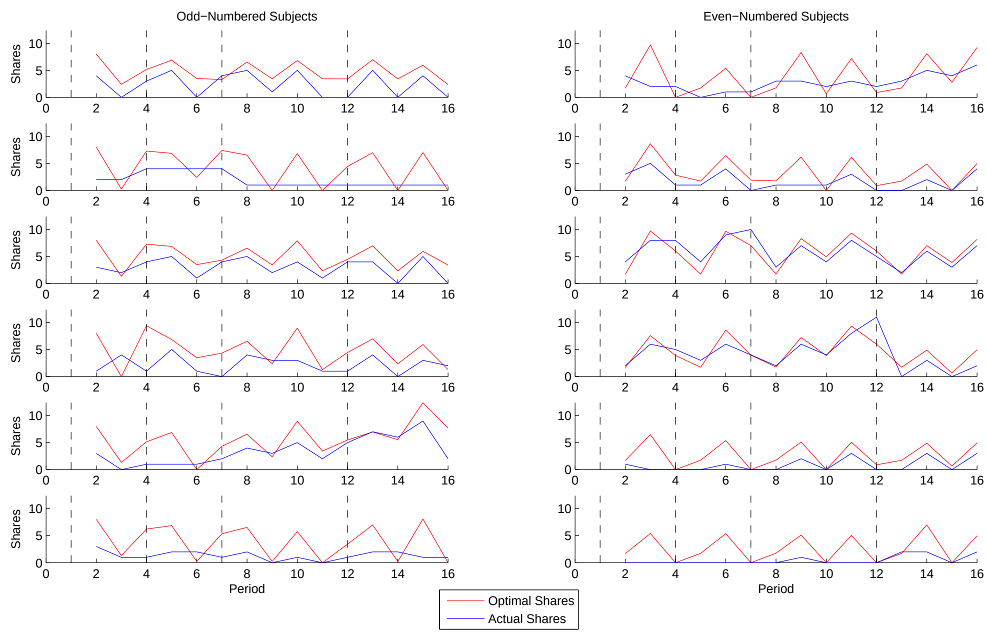


Figure 8: Actual vs. Optimal Shares in Session 2

Three patterns emerge from the data. (1) Some subjects behave like risk-neutral optimizers, particularly in session 6 where prices were near the fundamental price. A second group of subjects do smooth consumption, but tend to buy less than is risk-neutral optimal in high income periods and sell more than is optimal in low income periods. This behavior seems like risk-aversion. A third group of subjects buy less than the optimal quantity in high income periods but sell less than or equal to the optimal quantity in the low income periods. This may be evidence of loss aversion, as purchases during high income periods can be considered potential losses, and sales during low income periods can be considered potential gains.

6 Conclusion

Surprisingly little is known about the causes of asset price bubbles yet there appears to be a broad consensus among economists that asset price bubbles periodically arise and can be associated with large welfare gains and losses. An understanding of the conditions under which asset price bubbles may or may not arise should therefore be of critical importance not only to economists but also to households, firms, government policy-makers and all other asset market participants. In developing laboratory environments where bubbles can be "turned off" or "turned on" we can give greater credence to the possible explanations for asset price bubbles. For instance, as our preliminary findings suggest, in environments with strong motives for asset trading and persistent bankruptcy risk, asset prices may follow paths that are close to those predicted by fundamentals, while in the absence of such motives (as in SSW), price bubbles and crashes may be the norm.

Further, as noted earlier, our proposed research provides an important bridge between the literature on experimental methods and experimental asset pricing models, and the literature on equilibrium asset pricing models used by macroeconomic/business cycle and finance researchers. To date there has been little communication between these two fields. Our work integrating methods and models from both fields will enable both literatures to speak to a broader audience.

Of course, much work remains to be done on the present project. At a minimum we will run six more sessions, three concave and three linear. We will expand the formal analysis of indigenous risk preferences and perform statistical analyses of the results, both at the market and individual levels. In future research we anticipate at least two distinct directions. In the first, the experimental design can be moved a step closer to the environments used in the macrofinance literature; specifically, by adding a known, two-state stochastic process for dividends, and/or a known, constant growth rate in endowment income. The purpose of such treatments would be to explore the robustness of our present findings in the deterministic setting to stochastic or growing environments.

In the other direction, it could prove quite useful to clarify the impact of features of our experimental design relative to the much-studied experimental design of SSW. For example, it would be interesting to focus on the role played by bankruptcy risk (time discounting) in inhibiting bubble formation using an experimental design that is more closely related to SSW than to the equilibrium consumption-based asset pricing model. For example, one could study a finite horizon, lump-of-money, linear (induced) utility design as in SSW, but where there exists a constant probability of bankruptcy. Would bubbles be observed in this environment, or is the chance of bankruptcy sufficient to keep prices grounded? We believe our current project and subsequent extensions could suggest paths forward for incorporating the potential for speculative asset price bubbles in the macroeconomics and finance literature.

References

Asparouhova, Elena, Peter Bossaerts, and Charles R. Plott (2003), "Excess Demand and Equilibration in Multi-Security Financial Markets: The Empirical Evidence," *Journal of Financial Markets* 6, 1-21.

Bossaerts, Peter and Charles R. Plott (2002), "The CAPM in thin experimental financial markets," *Journal of Economic Dynamics and Control* 26, 1093-1112.

Bossaerts, Peter Charles R. Plott and William R. Zame (2007), "Prices and portfolio choices in financial markets: Theory, econometrics, experiments," *Econometrica* 75, 993-1038.

Breeden, Douglas T. (1979), "An intertemporal asset pricing model with stochastic consumption and investment opportunities," *Journal of Financial Economics* 7, 265–296.

Camerer, Colin and Keith Weigelt (1993), "Convergence in experimental double auctions for stochastically lived assets," in D. Friedman and J. Rust, Eds., *The Double Auction Market: Institutions, Theories and Evidence* Cambridge, MA: Perseus Publishing, 355-396.

Dufwenberg, Martin, Tobias Lindqvist, and Evan Moore (2005), "Bubbles and experience: An experiment," *American Economic Review* 95, 1731-37.

Fischbacher, Urs (2007), "z-Tree: Zurich toolbox for ready-made economic experiments," *Experimental Economics* 10, 171-178.

Forsythe, Robert, Thomas Palfrey and Charles R. Plott (1982), "Asset valuation in an experimental market," *Econometrica* 50, 537-567.

Friedman, Daniel, Glenn Harrison and Jon Salmon (1984), "The informational efficiency of experimental asset markets," *Journal of Political Economy* 92, 349-408.

Hansen, Lars P., and Kenneth J. Singleton (1983), "Stochastic consumption, risk aversion and the temporal behavior of asset returns," *Journal of Political Economy* 91, 249-265.

Harrison, Glenn W., Morten I. Lau, Elisabet E. Rutstrom, and Melanie B. Sullivan, "Eliciting risk and time preferences using field experiments: Some methodological issues," in J. Carpenter, G.W. Harrison, and J.A. List (eds.), *Field Experiments in Economics* (Greenwich, CT: JAI Press, Research in Experimental Economics, Volume 10, 2005).

Haruvy, Ernan, Yaron Lahav and Charles N. Noussair (2007), Traders' expectations in asset markets: Experimental evidence. *American Economic Review*, 97, 1901-1920.

Holt, Charles A., and Susan K. Laury (2002), "Risk aversion and incentive effects in lottery choices," *American Economic Review* 92, 1644-1655.

Holt, Charles A., and Susuan K. Laury (2005), "Risk aversion and incentive effects: New data without order effects" *American Economic Review* 95(3), 902-912.

Kocherlakota, Narayana R. (1996), "The equity premium: It's still a puzzle," *Journal of Economic Literature* 34, 42-71.

Lei, Vivian, Charles N. Noussair and Charles R. Plott (2001), "Nonspeculative bubbles in experimental asset markets: Lack of common knowledge of rationality vs. actual irrationality," *Econometrica* 69, 831–59.

Lengwiler, Yvan (2004), Microfoundations of Financial Economics, Princeton: Princeton University Press.

LeRoy, Stephen F. and Richard D. Porter (1981), "The present value relation: Tests based on implied variance bounds," *Econometrica*, 49, 555—574.

Lucas, Robert E. Jr., (1978), "Asset prices in an exchange economy," *Econometrica* 46, 1429–1445.

Mankiw, N. Gregory and Stephen P. Zeldes, (1991), "The consumption of stockholders and nonstockholders," *Journal of Financial Economics*, 29, 97-112.

Noussair, Charles N. and Kenneth J. Matheny (2000), "An experimental study of decisions in dynamic optimization problems," *Economic Theory* 15, 389-419

Plott, Charles R. and Vernon L. Smith (2008), Eds., *Handbook of Experimental Economic Results* Vol.1, Amsterdam: North Holland.

Plott, Charles R. and S. Sunder (1982), "Efficiency of experimental security markets with insider trading," *Journal of Political Economy* 90, 663-698.

Porter, David P. and Vernon L. Smith (1995), "Futures contracting and dividend uncertainty in experimental asset markets," *Journal of Business* 68, 509-541.

Shiller, Robert J. (1981), Do stock prices move too much to be justified by subsequent changes in dividends?" *American Economic Review*, 71, 421—436.

Smith, Vernon L. (1962), "An experimental study of competitive market behavior," *Journal of Political Economy* 70, 111-137.

Smith, Vernon L., Gerry L. Suchanek, and Arlington W. Williams (1988), "Bubbles, crashes and endogenous expectations in experimental spot asset markets," *Econometrica* 56, 1119-51.

Stiglitz, Joseph E. (1970), "A consumption-oriented theory of the demand for financial assets and the term structure of interest rates," *Review of Economic Studies* 37, 321-351.

Wheatley, S. (1988), "Some tests of the consumption-based asset pricing model," *Journal of Monetary Economics* 22, 193—215.