Title
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Journal
The Review of Economic Studies, 86(2)

ISSN
0034-6527

Authors
Crockett, Sean
Duffy, John
Izhakian, Yehuda

Publication Date
2019-03-01

DOI
10.1093/restud/rdy035

Peer reviewed

An Experimental Test of the Lucas Asset Pricing Model

Sean Crockett[*], John Duffy[†], and Yehuda Izhakian[‡§]

June 18, 2018

Abstract

We implement a dynamic asset pricing experiment in the spirit of Lucas (1978) with storable assets and non-storable cash. In the first treatment, we impose diminishing marginal returns to cash to incentivize consumption smoothing across periods. We find that subjects use the asset to smooth consumption, although the asset trades at a discount relative to the risk-neutral fundamental price. This under-pricing is a departure from the asset price "bubbles" observed in the large experimental asset pricing literature originating with Smith et al. (1988) and can be rationalized by considering subjects' risk aversion with respect to uncertain money earnings. In a second treatment, with no induced motivation for trade à la the Smith et al. design, we find that the asset trades at a premium relative to its expected value and that shareholdings are highly concentrated. Elimination of asset price uncertainty in additional experimental treatments serves to reinforce the same observations, and suggests that speculative behavior explains the departure of prices from fundamental value in the absence of a consumption-smoothing motive for asset trades.

Keywords: Asset Pricing, Lucas Tree Model, Experimental Economics, General Equilibrium, Intertemporal Choice, Macrofinance, Consumption Smoothing.

JEL Classification Numbers: C90, D51, D91, G12.

[*]Baruch College, City University of New York; sean.crockett@baruch.cuny.edu

[†]University of California, Irvine; duffy@uci.edu

[‡]Baruch College, City University of New York; yud@stern.nyu.edu;

[§]For useful comments and suggestions, we thank the editor, Dimitri Vayanos, and four anonymous referees, as well as Elena Asparouhova, Peter Bossaerts, Craig Brown, Guillaume Frechette, John Geanakoplos, Steven Gjerstad, David Porter, Stephen Spear and seminar participants at various conferences and universities. We thank Jonathan Lafky for assistance with programming the experiment. Funding for this project was provided by the Dietrich School of Arts and Sciences of the University of Pittsburgh. Crockett acknowledges funding from the National Science Foundation under grant SES-1357895.

1 Introduction

Consumption-based general equilibrium asset pricing, pioneered by Stiglitz (1970), Lucas (1978), and Breeden (1979), remains a workhorse model in financial economics and macrofinance. This approach relates asset prices to risk and time preferences, dividend payments, and other fundamental determinants of asset values.[1] While this class of theoretical models has been extensively tested using archival field data, the evidence to date has not been too supportive of the models' predictions. Estimated or calibrated versions of the standard model generally under-predict the actual premium in the return to equities relative to bonds, the so-called "equity premium puzzle" (e.g., Hansen and Singleton 1983, Mehra and Prescott 1985, and Kocherlakota 1996). Furthermore, the actual volatility of asset prices is typically much greater than the model's predicted volatility based on changes in fundamentals alone, the so-called "excess volatility puzzle" (Shiller 1981, and LeRoy and Porter 1981).[2]

A difficulty with testing this model using field data is that important parameters are unknown and must be calibrated, approximated, or estimated in some fashion. An additional difficulty is that the available field data (e.g., aggregate consumption data) may be subject to measurement error (Wheatley 1988) or may not approximate well the consumption of asset market participants (Mankiw and Zeldes 1991). A typical approach is to specify a dividend process and calibrate individuals' preferences to this process using micro-level data. However, micro-level data may not be directly relevant to the domain or frequency of the data examined in macrofinance studies.

We follow a different path by analyzing data from a laboratory experiment with controlled income and dividend processes, allowing for precise measurement of consumption and asset holdings. We induce the stationarity associated with the Lucas model's infinite horizon and time discounting by implementing an indefinite horizon with a constant continuation probability. In addition, we induce heterogeneity in consumer types to create a clear motivation for subjects to engage in trade.[3] The degree of control afforded by the laboratory presents an opportunity to diagnose the causes of specific deviations from theory, which are not identifiable using field data alone.

Most previous dynamic asset pricing experiments depart in significant ways from consumption-based models.[4] In the early literature (e.g., Forsythe et al. 1982, Plott and Sunder 1982, and Friedman et al. 1984), cyclic type-dependent dividends are induced to motivate trade, resulting in market prices

[1] For surveys, see e.g., Campbell (2018), Cochrane (2005) and Lengwiler (2009).

[2] Nevertheless, Cochrane (Page 455, 2005) stresses that while the consumption-based model "*works poorly in practice (...) it is in some sense the only model we have. The central task of financial economics is to figure out what are the real risks that drive asset prices and expected returns. Something like the consumption-based model–investor's first-order conditions for savings and portfolio choice–has to be the starting point.*"

[3] In this respect, we deviate from the theoretical literature, which frequently presumes a representative agent and derives equilibrium asset prices at which the equilibrium volume of trade is zero.

[4] Some studies test the static capital-asset pricing model (CAPM) over multiple repetitions; e.g., Bossaerts and Plott (2002), Asparouhova et al. (2003), and Bossaerts et al. (2007).

that effectively aggregate private dividend information and converge toward rational expectations values. While this result is in line with the efficient markets view, the primary motivation for exchange is not intertemporal consumption-smoothing as in the Lucas model.

In later, highly influential work, Smith et al. (SSW, 1988) implement a simple four-state i.i.d. dividend process common to all subjects. A finite number of trading periods ensures that the expected value of the asset declines over time at a constant rate. Unlike the earlier type-dependent dividend experiments, there is no induced motive for subjects to engage in any trade in the asset. Nevertheless, SSW observe substantial trading, with prices typically starting below the fundamental value then rapidly soaring above for a sustained duration of time before finally collapsing near the known final period of the experiment. This "bubble-crash" pattern has been replicated in many studies under a variety of treatment conditions, and has become the primary focus of a large experimental literature on asset price formation.[5] Much attention has been devoted to exploring the means by which the frequency of bubbles can be reduced or even eliminated by using some variants of the SSW design.[6,7]

Experiments in the SSW tradition share the following features. Subjects are given a large, one-time endowment (or loan) of experimental cash, called "francs." Thereafter, an individual's franc balance varies with her asset purchases, sales, and earned dividends. Francs carry over from one period to the next over the finite horizon of the market. Following the terminal period, franc balances are converted into money earnings using a linear exchange rate. This design differs from the sequence of consumption/savings choices faced by consumers in standard infinite horizon intertemporal models; in essence, it abstracts from the consumption-smoothing rationale for trade in assets.

By contrast, subjects in our experiment receive an exogenous endowment of francs at the start of each period, which we interpret as income, in addition to franc-denominated dividend payments on assets held. Then, an asset market is opened, with each transaction impacting the subject's franc balances. Critically, after the asset market is closed, each subject's end-of-period franc balance is converted to dollars and stored in a private payment account from which the subject cannot withdraw during the experiment, while her asset position carries forward to the next period with a fixed and known probability. Thus, all francs disappear from the system at the end of each period. That is, in the language of Lucas (1978) francs are perishable "fruit" that get consumed each period, while assets

[5] Key papers include Porter and Smith (1995), Lei et al. (2001), Dufwenberg, et al. (2005), Haruvy and Noussair (2006), Haruvy et al. (2007), Hussam et al. (2008), Lei and Vesely (2009), Lugovskvy et al. (2011) and Kirchler et al. (2012). For a review of the literature, see Plott and Smith (Chapters 29-30, 2008).

[6] These variants include adding short sales or futures markets, computing expected values for subjects, implementing a constant dividend, inserting "insiders" who have previously experienced bubbles, using professional traders in place of students as subjects, framing the problem differently, or using different price determination mechanisms

[7] Hommes et al. (2005, 2008) employ a different intertemporal framework that exploited a no arbitrage condition between risky and risk-free assets. In each period, price forecasts from subjects are elicited and leveraged to calculate optimal individual demands for the risky asset. Equating aggregate demand with a fixed supply yields prices, against which forecasts are evaluated and compensated.

are potentially long-lived "trees."[8]

We motivate trade in our baseline ("concave") treatment by introducing a heterogeneous, cyclic income process and a concave franc-to-dollar exchange rate, so that the long-lived asset becomes a vehicle to intertemporally smooth consumption. This is a critical feature of most macrofinance models, which are built around the permanent income model of consumption, but it is absent from the experimental asset pricing literature. In our alternative ("linear") treatment, the franc-to-dollar exchange rate is linear as in SSW-type designs; since the dividend process is common to all subjects, there is no induced reason for subjects to trade the asset, a design that connects our macrofinance economy with the laboratory asset market design of SSW. We show theoretically that if subjects are intrinsically risk neutral with regard to uncertain money earnings, the (constant) equilibrium price (henceforth the "fundamental price") in both our linear and concave exchange rate treatments is the same and is equal to the fundamental price in the analogous infinite horizon economy. Importantly, however, equilibrium consumption is characterized by perfect consumption smoothing in the concave treatment, and is unrestricted in the linear treatment. If subjects are instead intrinsically risk averse with regard to uncertain money earnings, we show theoretically that the equilibrium price in each period will be strictly less than the fundamental price, that prices will converge to a steady state equilibrium price that is weakly less than the fundamental price, and for a given distribution of risk preferences this steady state price will be the same in both the concave and linear treatments. To explore the role of risk aversion in our experiment, we measure subjects' intrinsic risk attitudes using the Holt-Laury (2002) paired lottery choice instrument.

While our experimental design mainly serves as a bridge between the experimental asset pricing and macrofinance literatures, it also has some relevance for laboratory research on intertemporal consumption-smoothing, which typically excludes tradeable assets.[9] A main finding of this literature is that subjects have difficulty intertemporally smoothing their consumption in the manner prescribed by the solution to a dynamic optimization problem. By contrast, in our experimental design, in which intertemporal consumption-smoothing is implemented by buying and selling assets at market-determined prices, we find strong evidence that subjects *are* able to smooth consumption in a manner that is qualitatively (if not quantitatively) similar to the dynamic equilibrium solution. This finding may also reflect the considerably simpler and non-stochastic income process that we use in our design.

Our main experimental findings can be summarized as follows. First, in our linear exchange rate treatment (where there is no induced motive for trade), prices are most frequently sustained at

[8] Notice that francs play a dual role as "consumption good" and "medium of exchange" within a period, while assets are the only *intertemporal* store of value.

[9] See, e.g., Hey and Dardanoni (1988), Noussair and Matheny (2000), Ballinger et al. (2003), Carbone and Hey (2004), Carbone and Duffy (2014), and Meissner (2016).

levels above the fundamental price (on average, 32% above). However, the frequency, magnitude, and duration of such price bubbles is dramatically reduced in our concave exchange rate treatment, where assets trade at an average discount of 24% relative to the fundamental price. The higher prices in the linear economies are driven by a concentration of shareholdings among the most risk-tolerant subjects in the market, identified by the Holt-Laury elicitation. By contrast, in the concave economies, most subjects actively trade shares in each period to smooth their consumption in the manner predicted by theory. Consequently, shareholdings are much less concentrated. Thus, market thin-ness and high prices appear to be endogenous features of the linear treatment. We conclude that the frequency, magnitude, and duration of asset price bubbles can be reduced by the presence of an incentive to intertemporally smooth consumption, a key feature of most dynamic asset pricing models that is completely absent from the SSW design used in the experimental asset pricing literature.

To better understand individual consumption and savings decisions, we conduct an additional, *individual choice* experiment in which subjects can buy or sell assets with the experimenter at a known, constant price. In this experiment, the only uncertainty each subject faces is the duration of the planning horizon; their endowments and the exchange rates remain the same as in the market experiment. We observe that the removal of price uncertainty strengthens the main findings from our market experiment. Namely, individuals facing a concave exchange rate use the asset to intertemporally smooth their consumption, while those facing a linear exchange rate adopt far more heterogeneous positions. Further, subjects facing high prices in the linear exchange rate condition are less likely to hold large share quantities, relative to the market experiment, suggesting that speculative motives account for the bubbles observed in the linear market experiment.

In related, concurrent research, Asparouhova et al. (2016) implement a Lucas asset experiment in which there are short-lived francs and <u>two</u> long-lived assets: trees yielding stochastic dividends and risk-free (consol) bonds. Rather than induce consumption smoothing through a concave exchange rate, subjects in their experiment are paid only for francs held in the terminal period of the indefinite horizon. Thus, Asparhouhova et al. rely on intrinsic subject risk aversion to smooth consumption; i.e., a risk-averse subject should avoid holding too few francs in any period in case that period is the terminal one. Asparouhova et al. use endogenous consumption-smoothing to investigate important questions in finance like the equity premium puzzle and the co-variation of financial returns with aggregate wealth. By contrast, we focus on the comparative static impact of consumption-smoothing when such incentives are exogenously weak or strong, bridging the gap between the consumption-based Lucas asset pricing model and the experimental literature initiated by SSW. Like Asparouhova et al., we find some qualified support for the predictions of the Lucas asset pricing model, in that price realizations are consistent with competitive equilibrium levels when there is an induced motive

to intertemporally smooth consumption and taking into account subject's intrinsic risk aversion.

2 The Lucas asset pricing framework

In this section, we first describe a Lucas (1978) infinite horizon economy. We then consider the indefinite horizon analog that we use in our experiment. Finally, we introduce the special case of constant dividend payments, a fixed aggregate endowment, and deterministic individual income, which are features of our experimental design. For this case, we prove convergence to a steady state equilibrium in which the price is weakly less than the fundamental price of the asset, provided weakly risk-averse intrinsic preferences.

2.1 Infinite horizon model

Consider a Lucas (1978) pure exchange economy, comprised of a non-storable consumption good (fruit) and an infinitely-lived asset (tree). At each discrete time, t, there is a fixed, finite and perfectly divisible number of outstanding shares, K, of the asset. Each share yields an identical but potentially time-dependent dividend, D_t, in period t. Dividends are paid in units of the consumption good at the beginning of each period. Let P_t denote the "ex-dividend" price of a share, i.e., if the share is sold, the sale occurs after the existing owner receives that period's dividend D_t. Neither borrowing nor short selling is permitted. Ownership of shares is determined each period in a competitive market. Denote by k_t^i the number of shares of the asset that consumer i owns at the beginning of period t, with initial endowment k_0^i.

In each period the economy has a finite population, L, of consumers. Each consumer i is characterized by a strictly monotonic, strictly concave, bounded, and twice continuously differentiable instantaneous utility function $\mathrm{U}^i : \mathbb{R}_+ \to \mathbb{R}$ that vanishes at zero.[10] That is, $\mathrm{U}^{i\prime}\ c_t^i\ > 0$, $\mathrm{U}^{i\prime\prime}\ c_t^i\ < 0$, and $\mathrm{U}^i(0) = 0$, where c_t^i is the consumption of perishable goods by consumer i at time t.

In addition to the dividend payment, each consumer receives an exogenous endowment of the consumption good, denoted y_t^i, at the beginning of each period t. This endowment may vary from period to period and may be different across consumers. Thus, the total resources available to each consumer in a given period are the exogenous endowment, plus the sum of dividends, plus (minus) the sale (purchase) value of assets shares. Formally,

$$\underbrace{y_t^i + \mathrm{D}_t k_t^i + \mathrm{P}_t k_t^i}_{\text{Resources}} \quad = \quad \underbrace{c_t^i + \mathrm{P}_t k_{t+1}^i}_{\text{Usage}}, \tag{1}$$

which implies that

$$k_{t+1}^i \quad = \quad \left(1 + \frac{\mathrm{D}_t}{\mathrm{P}_t}\right) k_t^i + \frac{1}{\mathrm{P}_t}\left(y_t^i - c_t^i\right). \tag{2}$$

[10] $\mathbb{R}_+$ stands for the set of nonnegative real numbers, i.e., $\mathbb{R}_+ = \{x \mid x \geq 0, x \in \mathbb{R}\}$.

Equation (1) also implies the market clearing conditions

$$K = \sum_i k_t^i \qquad \text{and} \qquad C_t = \sum_i c_t^i, \tag{3}$$

for every t. Since endowment and dividends cannot be stored and the utility function is strictly monotonic, these resources are completely consumed in each period. That is,

$$C_t = Y_t + \mathrm{D}_t K, \tag{4}$$

where $Y_t = \sum_i y_t^i$ is the aggregate endowment in the economy at time t.

Each consumer, i, faces the following objective function,

$$\begin{aligned} \mathrm{v}^i \; m_0^i &= \max_{\{c_t^i\}_{t=0}^{\infty}} \mathbb{E}_0^i \sum_{t=0}^{\infty} \beta^t \mathrm{U}^i\left(c_t^i\right) \\ \text{s.t.} \quad k_{t+1}^i &= \left(1 + \frac{\mathrm{D}_t}{\mathrm{P}_t}\right) k_t^i + \frac{1}{\mathrm{P}_t}\left(y_t^i - c_t^i\right) \\ m_{t+1}^i &= \left(\mathrm{P}_{t+1} + \mathrm{D}_{t+1}\right) k_{t+1}^i \end{aligned} \tag{5}$$

where, to rule out non-fundamental solutions, the transversality condition $\lim_{\tau\to\infty} \mathbb{E}_t^i\left[\beta^\tau \mathrm{U}^{i\prime}\left(c_{t+\tau}^i\right)\left(\mathrm{P}_{t+\tau} + \mathrm{D}_{t+\tau}\right) k_{t+\tau}^i\right] = 0$ is assumed to hold.[11] The coefficient $\beta \in (0,1)$ is the (common) period discount factor, and $\mathbb{E}_t^i[\cdot]$ stands for the expectation conditional upon the information set (beliefs) available to consumer i at time t. The variable m_{t+1}^i denotes the value of resources consumer i chooses to transfer to time $t+1$ via the shareholdings that she adopts at time t. By the strict monotonicity of U^i, the budget constraint of each consumer i is binding in equilibrium. That is,

$$c_t^i = y_t^i + \left(\mathrm{P}_t + \mathrm{D}_t\right) k_t^i - \mathrm{P}_t k_{t+1}^i. \tag{6}$$

Since neither borrowing nor short selling are permitted, we must have that $c_t^i \geq 0$ and $k_t^i \geq 0$. Hence, when the solution to the maximization problem in Equation (5) implies $c_t^i < 0$ or $k_t^i < 0$, a boundary solution is obtained since utility functions are strictly monotonic. The same holds when the solution implies that $k_t^i > K$. Henceforth, we focus on characterizing the unique *interior* equilibrium solution.

The consumer's maximization problem in Equation (5) can be rewritten in the form of Bellman's (recursive) equation

$$\mathrm{v}^i\left(m_t^i\right) = \max_{\{c_t^i\}} \mathrm{U}^i\left(c_t^i\right) + \beta \mathbb{E}_t^i\left[\mathrm{v}^i\left(m_{t+1}^i\right)\right], \tag{7}$$

with the transversality condition $\lim_{\tau\to\infty} \beta^\tau \mathbb{E}_t^i\left[\mathrm{v}^{i\prime} \; m_{t+\tau}^i \; m_{t+\tau}^i\right] = 0$. Suppose the value function, v^i, is differentiable. The first order condition (FOC) for an interior solution at each time $t = 1, 2, 3 \ldots$ is

$$0 = \mathrm{U}^{i\prime}\left(c_t^i\right) - \beta \mathbb{E}_t^i\left[\mathrm{v}^{i\prime}\left(m_{t+1}^i\right) \frac{\mathrm{P}_{t+1} + \mathrm{D}_{t+1}}{\mathrm{P}_t}\right], \tag{8}$$

[11] When U^i is linear, the transversality condition need not hold; in that case, non-fundamental bubble solutions are possible.

for every consumer i. By the Envelope Theorem (e.g., Milgrom and Segal (2002)),

$$\mathrm{v}^{i\prime}\left(m_{t+1}^{i}\right) \quad = \quad \mathrm{U}^{i\prime}\left(c_{t+1}^{i}\right). \tag{9}$$

Thus, the FOC in Equation (8) becomes

$$\mathrm{P}_{t}^{*} \quad = \quad \beta\mathbb{E}_{t}^{i} \ \frac{\mathrm{U}^{i\prime} \ c_{t+1}^{i}}{\mathrm{U}^{i\prime} \ c_{t}^{i}}\left(\mathrm{P}_{t+1}+\mathrm{D}_{t+1}\right) \quad , \tag{10}$$

which, by applying the law of iterated expectations, can be rewritten as

$$\mathrm{P}_{t}^{*} \quad = \quad \mathbb{E}_{t}^{i} \ \underset{\tau=1}{\overset{\infty}{}} \beta^{\tau}\frac{\mathrm{U}^{i\prime} \ c_{t+\tau}^{i}}{\mathrm{U}^{i\prime} \ c_{t}^{i}}\mathrm{D}_{t+\tau} \quad . \tag{11}$$

The term $\beta\frac{\mathrm{U}^{i\prime}\left(c_{t+\tau}^{i}\right)}{\mathrm{U}^{i\prime}\left(c_{t}^{i}\right)}$ is referred to as the stochastic discount factor, and the term $\frac{\mathrm{U}^{i\prime}\left(c_{t+\tau}^{i}\right)}{\mathrm{U}^{i\prime}\left(c_{t}^{i}\right)}$ is referred to as the intertemporal marginal rate of substitution.

Equation (11) does not assume a particular form for the utility function U^{i}, and must hold for any equilibrium price function.[12] When all consumers have the same utility function and beliefs, Equation (11) holds for such a "representative" consumer.[13] Because the utility function is strictly monotonic, markets clear. Finally, by Lucas (Proposition 1, 1978), the pairs $\mathrm{v}\left(m_{t}\right)$ and P_{t}^{*}, which are the solution to the maximization problem in Equation (5), define a unique equilibrium.

2.2 Indefinite horizon model with induced preferences

Since we cannot study an infinite number of periods in the laboratory, we move to a related *indefinite horizon* setting, where the economy continues to the next period with a known, constant probability, π. The economy remains comprised of perishable "fruit" and a fixed number of asset shares in a potentially long-lived "tree." Fruit (endowment income, dividends, and net income from the sale of shares) is denominated in an experimental currency called "francs." Consumption involves the conversion of these franc balances into real money earnings ("dollars") using the exchange function $\mathrm{u}^{i}:\mathbb{R}_{+}\rightarrow\mathbb{R}_{+}$ at the end of each period. This exchange function is strictly monotonic, strictly concave, bounded, twice continuously differentiable, and vanishes at zero.[14]

The exchange function is applied to control a consumer's objective function and provide incentives to consume. A concave u^{i} induces a diminishing marginal utility of consumption and motivates consumption smoothing through trade in the asset market. Thus, henceforth, we refer to u^{i} as an "induced utility" function and to the concavity of u^{i} as "induced risk aversion." By contrast, we will

[12] Recall that, in equilibrium, the price of assets must be such that each consumer does not want to modify her asset holdings at any time t.

[13] À la Constantinides (1982), a representative investor can be defined as an artificial investor whose tastes and beliefs are such that if all investors in the economy had tastes and beliefs identical to his, the equilibrium in the economy remains unchanged. When consumers have heterogeneous beliefs or utility functions, the existence of a representative investor requires either the market be complete (Dybvig and Ingersoll, 1982), or consumers have homogeneous beliefs and time-additive utility functions (Constantinides, 1980).

[14] That is, $\mathrm{u}^{i\prime}\left(\cdot\right)>0$, $\mathrm{u}^{i\prime\prime}\left(\cdot\right)<0$ and $\mathrm{u}^{i}\left(0\right)=0$.

henceforth refer to U^i as the unobserved "intrinsic" (or homegrown) utility function of consumer i. Later, we show that the function u^i effectively plays a role similar to U^i in Equation (11) when consumers are intrinsically risk neutral, but we will also consider cases where consumers are intrinsically risk averse.

In each period t, consumer i chooses a quantity, s_t^i, of francs to convert (save) into dollars, $c_t^i = \mathrm{u}^i \ s_t^i$, which is added to her accumulated consumption quantity (experimental earnings) $\zeta_t^i = \underset{\tau=0}{\overset{t}{\ }} c_\tau^i$. These consumption earnings are not available to use during the experiment (dollars accrue in a virtual lock box); at the end of the experiment a subject's cumulative balance is paid in cash. At the end of each period a lottery determines whether the economy continues to the next period with probability π or ends with probability $1-\pi$. If the economy ends, then all asset shares vanish and consumption of the accumulated dollars takes place.[15] If the economy continues, then shareholdings carry over to the next period.

In this indefinite horizon economy, each consumer i faces the maximization problem

$$\begin{aligned} \mathrm{v}^i \ m_0^i &= \max_{\{s_t^i\}_{t=0}^{\infty}} \mathbb{E}_0^i \underset{t=0}{\overset{\infty}{\ }} (1-\pi)\,\pi^t \beta^t \mathrm{U}^i\left(\zeta_t^i\right) \qquad (12) \\ \text{s.t.} \quad k_{t+1}^i &= \left(1+\frac{\mathrm{D}_t}{\mathrm{P}_t}\right) k_t^i + \frac{1}{\mathrm{P}_t}\left(y_t^i - s_t^i\right) \\ m_{t+1}^i &= \left(\mathrm{P}_{t+1}+\mathrm{D}_{t+1}\right) k_{t+1}^i \\ \zeta_t^i &= \underset{\tau=0}{\overset{t}{\ }} c_\tau^i \\ c_t^i &= \mathrm{u}^i\left(y_t^i + \mathrm{D}_t k_t^i + \mathrm{P}_t\left(k_t^i - k_{t+1}^i\right)\right), \end{aligned}$$

where the transversality condition $\lim_{\tau\to\infty} \mathbb{E}_t^i\left[(1-\pi)\,\pi^\tau\beta^\tau \mathrm{U}^{i\prime}\left(\zeta_{t+\tau}^i\right) \mathrm{u}^{i\prime}\left(s_{t+\tau}^i\right)\left(\mathrm{P}_{t+\tau}+\mathrm{D}_{t+\tau}\right) k_{t+\tau}^i\right] = 0$ is assumed to hold.[16] The first constraint can be rewritten to define the quantity of francs that consumer i converts into dollars (saves) at time t,

$$s_t^i = y_t^i + \mathrm{D}_t k_t^i + \mathrm{P}_t\left(k_t^i - k_{t+1}^i\right). \qquad (13)$$

Since both u^i and U^i are strictly monotonic, this budget constraint is always binding.

The maximization problem in Equation (12) can be rephrased in the form of the Bellman's (recursive) equation

$$\mathrm{v}^i\left(m_t^i\right) = \max_{\{s_t^i\}} (1-\pi)\,\mathrm{U}^i\left(\zeta_t^i\right) + \pi\beta\mathbb{E}_t^i\left[\mathrm{v}^i\left(m_{t+1}^i\right)\right] \qquad (14)$$

with the transversality condition $\lim_{\tau\to\infty} (1-\pi)\,\pi^\tau\beta^\tau\mathbb{E}_t^i\left[\mathrm{v}^{i\prime} \ m_{t+\tau}^i \ m_{t+\tau}^i\right] = 0$. The FOC of an interior

[15] In the experiment, subjects participate in several such indefinite horizon economies (which we call sequences). Thus, they are only paid their accumulated earnings following the last of these sequences.

[16] In the case where both U^i and u^i are linear–a possibility we allow for in our experiment–the transversality condition need not hold. However, even in that case, since the total resources of our experimental economy are held fixed, the transversality condition must nevertheless hold.

solution of this problem is then

$$0 \quad = \quad (1-\pi)\,\mathrm{U}^{i\prime}\left(\zeta_t^i\right)\mathrm{u}^{i\prime}\left(s_t^i\right) - \pi\beta\mathbb{E}_t^i\left[\mathrm{v}^{i\prime}\left(m_{t+1}^i\right)\frac{\mathrm{P}_{t+1}+\mathrm{D}_{t+1}}{\mathrm{P}_t}\right]. \tag{15}$$

By Lemma 1 (see Appendix),

$$\mathrm{v}^{i\prime}\left(m_{t+1}^i\right) \quad = \quad (1-\pi)\,\mathrm{U}^{i\prime}\left(\zeta_{t+1}^i\right)\mathrm{u}^{i\prime}\left(s_{t+1}^i\right). \tag{16}$$

Thus, for every time t, the equilibrium price satisfies

$$\mathrm{P}_t^* \quad = \quad \pi\beta\mathbb{E}_t^i \quad \frac{\mathrm{U}^{i\prime} \quad \zeta_{t+1}^i}{\mathrm{U}^{i\prime} \quad \zeta_t^i}\frac{\mathrm{u}^{i\prime} \quad s_{t+1}^i}{\mathrm{u}^{i\prime} \quad s_t^i}\left(\mathrm{P}_{t+1}+\mathrm{D}_{t+1}\right) \quad , \tag{17}$$

for all i, and, by the law of iterated expectations, can be rewritten as

$$\mathrm{P}_t^* \quad = \quad \mathbb{E}_t^i \quad \mathop{}_{\tau=1}^{\infty} \pi^\tau\beta^\tau\frac{\mathrm{U}^{i\prime} \quad \zeta_{t+\tau}^i}{\mathrm{U}^{i\prime} \quad \zeta_t^i}\frac{\mathrm{u}^{i\prime} \quad s_{t+\tau}^i}{\mathrm{u}^{i\prime} \quad s_t^i}\mathrm{D}_{t+\tau} \quad . \tag{18}$$

Notice that when all consumers are intrinsically risk neutral (i.e., when U^i is linear), and the length of a sequence is sufficiently short so that there is no impatience (i.e., $\beta = 1$), then Equation (18) simplifies to Equation (11) provided that: (i) The continuation probability, π, equals the (constant) discount factor in the infinite horizon model, and (ii) The induced utility function, u^i, in the indefinite horizon model matches the intrinsic period utility function, U^i, in the infinite horizon model of the last subsection. Thus, we may treat our indefinite horizon model as an induced preference implementation of the infinite horizon model of Subsection 2.1 under the assumption that consumers are intrinsically risk neutral with respect to the uncertain amounts of money they earn in our experiment.[17]

2.3 The model implemented in the laboratory

To implement the model described in the previous section in the laboratory, we make four additional assumptions. First, the dividend in every time period, t, is constant, $\mathrm{D}_t = \overline{\mathrm{D}}$.[18] Second, the endowment, y_t^i, that each consumer i receives is deterministic. Third, the aggregate endowment of income is constant over time, and this is common knowledge. Fourth, we assume that $\beta = 1$; since consumers cannot spend cumulative dollar earnings until the end of the experiment and savings do not earn any interest, there is no reason to treat dollars earned in different periods differently. The first three assumptions, along with the assumption we maintain throughout that aggregate shares are constant over time, imply that aggregate resources available for saving $S_t = \mathop{}_{i} s_t^i$ are held constant over time, so that $S_t = \overline{S}$ for all t. Summarizing these assumptions, we have

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[17] This distinction between induced and intrinsic risk aversion will prove useful later on in explaining our experimental findings and that is why we introduce it here.

[18] When the dividend is stochastic and consumers are strictly risk averse, it is straightforward to show that a steady state equilibrium price does not exist. Instead, the price will depend (at a minimum) upon the current realization of the dividend, which affects current consumption and accordingly the intertemporal marginal rate of substitution. Mehra and Prescott (1985) derive equilibrium pricing in a representative agent version of the infinite horizon model with a finite-state Markov dividend process.

Assumption 1. *Aggregate income and shares in the economy are constant, dividends are constant, individual endowment income is deterministic, and there is no time discounting.*

Under these design-motivated assumptions, any rational expectations equilibrium sequence of prices and allocations through period t is deterministic, conditional on reaching period t. We can thus discard the expectation operator, $\mathbb{E}_t^i[\cdot]$, in Equations (17) and (18); the only uncertainty is horizon uncertainty, i.e., whether period $t+\tau$ will be reached.

When the intrinsic utility function of all consumers is linear (i.e., consumers are intrinsically risk neutral), we next show the price in each period is equal to the **fundamental price**.

Proposition 1. *Suppose that Assumption 1 holds and the intrinsic utility,* U^i*, is linear for each consumer* i*. Then, the price in each period is constant and equal to the fundamental price*

$$\mathrm{P}_t^* \;=\; \frac{\pi\overline{\mathrm{D}}}{1-\pi} \;\equiv\; \overline{\mathrm{P}}^*. \tag{19}$$

Further, if the induced utility, u^i*, is strictly concave for each consumer* i*, then equilibrium savings satisfies*

$$s_t^i \;=\; s_{t+1}^i \;\equiv\; s^{i*}, \tag{20}$$

for every time t *and every consumer* i*. If instead* u^i *is linear, equilibrium savings are restricted only by the budget constraint.*

The proof of Proposition 1 and all subsequent Propositions can be found in Appendix A.

Proposition 1 demonstrates that when U^i is linear for every consumer i, the equilibrium price is equal to the expected value of the dividend stream and is *independent* of the induced utility function, u^i. Our experimental design exploits this independence result. Under the assumption that consumers are intrinsically risk neutral, we can vary the induced utility function and not alter the equilibrium price prediction. Indeed, as we discuss later in Section 3, our experiment compares and contrasts the case where the induced utility function is linear, as in the SSW experimental approach, with the case where the induced utility function is strictly concave, introducing a consumption-smoothing incentive for exchange which is the core feature of the Lucas model. Thus, our experimental design enables us to make a connection between the SSW design and the Lucas asset pricing model.

We next prove that if each consumer i is intrinsically risk averse, i.e., her intrinsic utility U^i is strictly concave, and if each consumer's induced utility function u^i is weakly concave, the equilibrium price in every period is strictly less than the fundamental price given by Equation (19). In this case, the certainty equivalent of the dividend stream flowing from the asset is less than its expected value for intrinsically risk-averse consumers.

Proposition 2. *Suppose that Assumption 1 holds, the intrinsic utility,* U^i*, is strictly concave, and*

the induced utility, u^i*, is weakly concave. Then, the equilibrium price at time* t *satisfies*

$$\mathrm{P}_t^* \quad < \quad \overline{\mathrm{P}}^*. \tag{21}$$

We next focus on a wide class of possible specifications for the intrinsic utility function, U^i; specifically, constant absolute risk aversion(CARA) and decreasing absolute risk aversion (DARA). For these specifications, we seek to identify comparative static implications from whether the induced utility function, u^i, is concave or linear. Specifically, we show that prices necessarily converge to a steady state equilibrium price, in the limit as t approaches infinity, independent of the induced utility function. Thus, the connection between the SSW experimental asset pricing framework and the Lucas asset pricing model extends to intrinsically risk-averse consumers; we are able to vary an induced incentive to smooth consumption while keeping the underlying steady state fundamentals unchanged.

We begin with the assumption that the intrinsic utility function, U^i, exhibits CARA, in which case accumulated wealth does not affect the consumer's current portfolio choice.[19] The CARA utility function can be specified as:

$$\mathrm{U}^i\left(\zeta_t^i\right) \quad = \quad \frac{1-e^{-\gamma^i \zeta_t^i}}{\gamma^i}. \tag{22}$$

Each consumer i's intrinsic risk aversion is summarized by a parameter $\gamma^i > 0$, where risk aversion is increasing in γ^i.

Proposition 3. *Suppose that Assumption 1 holds and each consumer* i *is strictly risk averse with CARA intrinsic utility,* U^i*. When the induced utility function,* u^i*, is weakly concave for every consumer* i*,*

$$\lim_{t\to\infty} \mathrm{P}_t^* \quad = \quad \frac{\pi \mathrm{D}}{e^{\gamma^i c^{i*}} - \pi} \quad \equiv \quad \mathrm{P}^* \quad < \quad \overline{\mathrm{P}}^*, \tag{23}$$

where $c^{i*} = \lim_{t\to\infty} c_t^i$*, for each consumer* i*. Further, when* u^i *is linear for every consumer* i*, the constant price and consumption specified in Equation* (23) *characterize a unique equilibrium at every time* $t > 1$*.*

This proposition implies that, when all intrinsic utility functions are strictly CARA, the economy converges to a unique steady state equilibrium in which the price, P^*, and consumption, c^{i*} (and thus savings, s^{i*}), of every consumer are constant over time. The steady state price is strictly less than the fundamental price and is implemented in the second and all subsequent periods if the induced utility function is linear.

Corollary 1. *Suppose that Assumption 1 holds, each consumer* i *is strictly risk averse with CARA intrinsic utility,* U^i*, and the induced utility function,* u^i*, is weakly concave for each* i*. Then, in a steady state equilibrium, consumer* i*'s savings,* s^{i*}*, is strictly decreasing in the risk aversion parameter* γ^i*. Further, the steady state equilibrium price is decreasing in* γ^i*.*

[19] Indeed, Sherstyuk et al. (2013) find no evidence of wealth effects for cumulative payment procedures such as the one we implement, which suggests that CARA may be a reasonable approximation for U^i.

Suppose now that all consumers have intrinsic DARA utility. That is, the consumers' risk aversion decreases as wealth increases. In this case, the equilibrium price sequence converges to the fundamental price from below, as the following proposition shows.

Proposition 4. *Suppose that Assumption 1 holds, each consumer i is strictly risk averse with DARA intrinsic utility, U^i, and the induced utility, u^i, is weakly concave for each i. Then, as time t tends to infinity, the economy converges to the fundamental price $\overline{\mathrm{P}}^*$. Further, when u^i is strictly concave, there exists a unique limiting saving allocation s^{i*} for every consumer i, while if instead u^i is linear, equilibrium savings are restricted only by the budget constraint.*

The recursive Equation (17) is typically under-determined. Yet, it is instructive to consider an example with an analytical solution. For that purpose, we assume that both the induced utility function, u, and the intrinsic utility function, U, exhibit homogeneous constant relative risk aversion (CRRA).[20] The CRRA utility function is specified by

$$\mathrm{U}\left(C_t^i\right) = \begin{array}{ll} \frac{\left(\zeta_t^i\right)^{1-\gamma}}{1-\gamma}, & \text{if} \quad \gamma \neq 1; \\ \ln\ \zeta_t^i & \text{if} \quad \gamma = 1. \end{array}$$

Proposition 5. *Suppose that Assumption 1 holds, the intrinsic utility, U^i, for each consumer i is CRRA with risk aversion parameter $\gamma > 0$, and the induced utility, u^i, for each consumer i is CRRA with curvature parameter $\delta \geq 0$. In addition, suppose there are an equal number of two types of consumers, who differ only in their endowments. Then the equilibrium price in period t is*

$$\mathrm{P}_t^* = \overline{\mathrm{D}} \sum_{\tau=t}^{\infty} \pi^{\tau-t+1} \left(\frac{\tau}{\tau+1}\right)^{\gamma} \tag{24}$$

Further, each consumer's consumption is constant across all periods.

This proposition implies that, when the intrinsic utility function is homogeneous and CRRA, each consumer perfectly smoothes her consumption over time. Further, neither the equilibrium price nor the savings allocation depends on the induced utility function. The equilibrium price sequence is monotonically increasing over time and converges to the fundamental price from below (consistent with Propositions 2 and 4) in the limit as t approaches infinity.

In summary, when consumers are intrinsically risk neutral, the equilibrium price in each period is equal to the fundamental price. When consumers are intrinsically risk averse, the equilibrium price in each period is strictly less than the fundamental price, and converges to a unique steady state equilibrium price and savings allocation. Concerning DARA intrinsic utility, the emergent price is equal to the fundamental price. Concerning CARA intrinsic utility, the emergent price is strictly less than the fundamental price. Concerning homogeneous CRRA utility, the equilibrium price can be characterized

[20] CRRA is a special case of DARA, which we use for our induced utility function in the experiment.

analytically for each period t, is strictly increasing over time, converges to the fundamental price (since CRRA utility is within the DARA class of utility functions), and does not depend on induced utility u.

2.4 Hypotheses

Based on the theory developed in Section 2.3, we present the following hypotheses, which we test in our experiment:

Hypothesis 1. *Prices in both the linear and concave induced utility treatments are weakly less than the fundamental price,* $\overline{\mathrm{P}}^*$.

An alternative hypothesis, inconsistent with the theoretical results of Section 2.3 but consistent with the large literature on asset price "bubbles" beginning with SSW, is the following:

Hypothesis 2. *Prices in the linear induced utility treatment exceed the fundamental price* $\overline{\mathrm{P}}^*$*, while prices in the concave induced utility treatment are weakly less than* $\overline{\mathrm{P}}^*$.

This alternative hypothesis can be motivated by belief heterogeneity. Consumer i's subjective beliefs, as reflected in the probabilities used to assess $\mathbb{E}_t^i[\cdot]$, impact the equilibrium price and allocation described by Equation (17). Scheinkman and Xiong (2003) and Hong et al. (2006) explore how heterogeneous beliefs about realized dividends can generate equilibrium prices exceeding an asset's fundamental value. An overconfident or optimistic buyer may consume less to buy more assets, to the point of holding the entire asset supply. While dividends are fixed in our experiment, optimism or overconfidence with respect to expected future prices may play a related role out of equilibrium. Alternatively, it is possible for consumers to subjectively and differently weight the continuation probability, π, (e.g., Kahneman and Tversky, 1979), which may also impact prices. Finally, there is the possibility that risk-seeking behavior drives prices above fundamentals.

We do not attempt to model these "bubble mechanisms." However, there are good reasons to think that heterogeneous beliefs may disproportionately impact choices when the induced utility function is linear as opposed to when it is concave, which are the two main treatments of our experiment (as described in the next section). Suppose that a subject's induced and intrinsic utility functions are both linear, and the subject holds the (rigid) belief in period t that $\mathrm{P}_{t+1} > \mathrm{P}_t > \mathrm{P}^*$. If this subject buys at date t and sells at date $t+1$, his expected gain is $\pi(\mathrm{P}_{t+1} + \overline{\mathrm{D}}) - \mathrm{P}_t$ per share. If this expected gain is positive, the subject would want to buy as many shares as possible in period t, and may choose to sell shares in the next period at P_{t+1} to other subjects who believe that prices will continue to appreciate beyond that period. Of course, given fixed franc resources, such bubbly expectations cannot be sustained indefinitely, but there can be a fairly long sequence of positive expected value draws, one

of which will result in termination with high probability.[21] Alternatively, a subject with these same beliefs pursuing the same speculative strategy would, under a concave induced utility function, be heavily penalized for the high variance in his period-by-period consumption levels that resulted from such speculation. Thus, the logic for Hypothesis 2 is that under a linear induced utility function we are more likely to see bubbly prices arising from heterogeneous beliefs while under a concave induced utility function, the individual's need to smooth consumption should dampen the extent of mispricing of the asset, so that prices should be more in line with our theoretical predictions.

When the induced utility function u^i is concave, consumers perfectly smooth their consumption provided that their intrinsic utility function is linear (risk neural) or in the DARA steady state equilibrium, while consumption is unrestricted for induced linear utility. However, in Proposition 5 we show that for intrinsically risk averse consumers there exist economies in which consumers perfectly smooth their consumption regardless of whether u^i is concave or linear. Consideration of these results leads us to the following hypothesis.

Hypothesis 3. *When the induced utility,* u^i*, is concave, subjects use the asset to intertemporally smooth their consumption to the same or to a greater extent than when* u^i *is linear.*

In addition, we consider two further hypotheses that follow from the previous section:

Hypothesis 4. *For a given induced utility function* u^i*, prices are higher in sessions with a higher dividend payment* $\overline{\mathrm{D}}$*.*

Hypothesis 5. *For a given induced utility function* u^i *and dividend, prices are lower in sessions with higher degrees of risk aversion as measured by Holt-Laury scores.*

3 Experimental design

We seek to determine the extent to which the price and shareholding predictions of the Lucas asset pricing model are supported in a laboratory experiment. Valuing shares in our indefinite horizon implementation is more complicated than in SSW, and in fact no participant possesses sufficient information to calculate the equilibrium price. Therefore, we assess the extent to which observed prices can be rationalized by knowledge of fundamentals alone, namely the asset's dividend, the continuation probability, the subject's induced utility function, and the subject's income process. Our experiment was designed with the intent of testing Hypotheses 1-5, as presented in the previous section.

[21] This scenario shares some features with the centipede game, in which backward induction and finite resources should induce "fundamental" behavior, yet experimental evidence (e.g., McKelvey and Palfrey, 1992) confirms a lack of backward induction reasoning relative to the complete information Nash equilibrium. It also shares some features of the "winner's curse," wherein the subject who believes the bubble will last the longest gets stuck holding the asset during the crash.

3.1 Income, dividends, and induced utility

We focus on two variations in model parameters. First, we examine whether changes in the value of the fixed dividend payment, $\overline{\mathrm{D}}$, affect the price of the asset, as theory asserts that a larger dividend payment—a fundamental factor—induces a higher steady state equilibrium price. Changing the dividend payment provides a simple test of a comparative statics prediction of the theory, as stated in Hypothesis 4.[22] Second, we examine whether the strength of the consumption-smoothing objective matters, by varying the curvature of the subjects' induced utility functions, u^i, over consumption. This latter treatment variation is novel to our design, and enables us to connect and differentiate our Lucas asset pricing model findings with results from SSW-inspired experiments. Changes in u^i are used to address Hypotheses 1-3.

We use a 2×2 design where the treatment variables are: 1) the induced utility function u^i, which is either strictly concave as in the Lucas model (page 1431, 1978) or linear as in SSW's approach; and 2) the dividend, $\overline{\mathrm{D}}$, which is either high or low. We conduct twenty laboratory sessions (five per treatment) of the indefinite horizon economy introduced in Sections 2.2 and 2.3. In each session, there are twelve subjects, six of each induced utility type, for a total of 240 subjects. The endowments and induced utility functions of the two subject types in all treatments are given in Table 1.

i	# Subjects	k_0^i	$\{y_t^i\}$	$\mathrm{u}^i(s_t^i)$
1	6	1	110 if t is odd 44 if t is even	$\delta^1 + \alpha^1 s_t^{\eta^1}$
2	6	4	24 if t is odd 90 if t is even	$\delta^2 + \alpha^2 s_t^{\eta^2}$

Table 1: **Induced Utility and Endowment Parameters**

In each session, the franc endowment, y_t^i, for each type $i \in \{1, 2\}$ follows the same deterministic two-cycle. Subjects are informed that the aggregate endowment of income and shares will remain constant throughout the session, but otherwise are only privy to information regarding their own income, shareholdings, and induced utility function. In each session, dividends take a constant value of either $\overline{\mathrm{D}} = 2$ or $\overline{\mathrm{D}} = 3$, and the induced utility function u^i is either linear or concave for both subject types. Thus, our four treatments are C2 (concave induced utility, $\overline{\mathrm{D}} = 2$), C3 (concave induced utility, $\overline{\mathrm{D}} = 3$), L2 (linear induced utility, $\overline{\mathrm{D}} = 2$), and L3 (linear induced utility, $\overline{\mathrm{D}} = 3$). We adopt a constant dividend framework since our primary motivation is to induce an economic incentive for trade in a standard macrofinance setting. Porter and Smith (1995) show that implementing constant dividends in the SSW design does not substantially reduce the incidence or magnitude of asset price bubbles.

[22] Alternatively, we could have changed other fundamental factors, such as the continuation probability, π. We chose to vary the dividend, as changes in the dividend process is a common treatment variation in the experimental asset pricing literature.

The induced utility parameters are chosen so that subjects earn \$1 per period at the (intrinsic) risk neutral competitive equilibrium in C2 and L2. By contrast, C2 subjects can earn, on average, \$0.45 per period in autarky (no trade). In L2, expected earnings in autarky equal the competitive equilibrium earnings due to the linear exchange rate. A higher dividend results in modestly higher benchmark payments. In L3 and C3, subjects earn on average \$1.06 per period in the risk neutral competitive equilibrium, while the autarkic payoff in C3 is on average \$0.58 per period. This doubling of payoffs between competitive equilibrium and autarky is chosen to make the differences salient to subjects, in line with prior research (Gneezy and Rustichini, 2000). The induced utility function used in each treatment is presented to the subjects both as a table and a graph (see Online Appendix).

In our baseline treatments C2 and C3, we set $\eta^i < 1$ and $\alpha^i \eta^i > 0$.[23] Given our cyclic income process, Equation (17) and the budget constraint can be used to show that risk neutral or DARA steady-state shareholdings follow a two-cycle between the initial share endowment, $k^i_{\text{Even}[t]} = k^i_0$, and

$$k^i_{\text{Odd}[t]} \quad = \quad k^i_{\text{Even}[t]} + \frac{y^i_{\text{Odd}[t]} - y^i_{\text{Even}[t]}}{2\overline{\text{P}}^* + \overline{\text{D}}}. \tag{25}$$

Notably, in the steady state, subjects smooth consumption by buying asset shares during high income periods and selling shares during low income periods. When $\overline{\text{D}} = 2$ by Equation (19), the fundamental price is $\overline{\text{P}}^* = 10$. In turn, Equation (25) implies that, at the fundamental price equilibrium, a type 1 subject in our C2 treatment holds 1 share in odd periods and 4 shares in even periods, and a type 2 subject holds 4 shares in odd periods and 1 share in even periods. When $\overline{\text{D}} = 3$, the fundamental price is $\overline{\text{P}}^* = 15$, and in equilibrium, a type 1 subject in our C3 treatment cycles between 1 and 3 shares, while a type 2 subject cycles between 4 and 2 shares.

Our primary variation on the baseline concave treatments is to set $\eta^i = 1$ for both agent types so that there is no longer an incentive to smooth consumption.[24] The linear treatments aim to examine an environment that is closer to the SSW framework. In SSW's design, the dividend process is common to all subjects and dollar payoffs are linear in francs, so intrinsic risk-neutral subjects have no induced motivation to engage in trade. Under (alternative) Hypothesis 2, in L2 and L3 assets will trade at prices greater than the fundamental price, $\overline{\text{P}}^*$, in line with SSW's bubble findings. This, however, contradicts our theoretical prediction (Hypothesis 1) that the curvature of induced utility has no impact on the steady state equilibrium price for subjects regardless of their induced utility treatment.

As is standard in asset market experiments, neither borrowing nor short selling is permitted; i.e., $s^i_t \geq 0$ and $k^i_t \geq 0$. In particular, we impose the following trading constraints:

$$y^i_t + \overline{\text{D}}_t k^i_t + \overline{\text{P}}_t \left(k^i_t - k^i_{t+1}\right) \geq 0, \qquad \text{and} \qquad k^i_t \geq 0.$$

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

[24] In these linear induced utility treatments, $\alpha^1 = 0.0122$, $\alpha^2 = 0.0161$, and $\delta^1 = \delta^2 = 0$.

The experiment is designed in such a way that these restrictions only bind out of equilibrium.

3.2 The continuation probability π

As noted earlier, we seek to induce the stationarity associated with an infinite horizon and constant time discounting by implementing an indefinite horizon with a stochastic number of trading periods.[25] Thus, from a subject's perspective, a share of the asset today is worth more than a share tomorrow not because she is impatient, but because the asset may cease to have value in the next period. In each period, trade takes place for three minutes in a centralized marketplace. At the end of each period, one subject in rotation takes a turn rolling a six-sided die in public view of the other participants. If the die roll in period t is between 1 and 5 inclusive, the economy continues for another period. In this case, each individual's asset position is carried over to the start of period $t+1$. If the die roll is 6, the economy terminates and all subjects' asset positions are declared worthless. Thus, the probability that assets continue to have value in future trading periods is $\pi = 5/6$.

Subjects are recruited for a three-hour session, during which they participate in several "sequences," each consisting of an indefinite number of three-minute "trading periods." Each sequence of trading periods ends upon a die roll of 6. We choose to have subjects participate in several indefinite sequences to better familiarize them with the role played by the continuation probability π. We instruct subjects that after one hour of play (following the reading of the instructions) the current sequence being played will be the final one; i.e., the next time a 6 is rolled the session will come to a close. This design ensures a reasonable number of trading periods, while at the same time limits the possibility that sessions last longer than the 3-hour recruitment window. Indeed, we never failed to complete the final sequence within the three hour time window for each session.[26] The expected mean (median) number of trading periods per sequence in this design is 6 (4), respectively. The realized mean (median) is 5.2 (4) in our sessions. On average there are 3.4 sequences per session.

Given π and our adopted values of $\overline{\mathrm{D}}$, the fundamental price of the asset in treatments C2 and L2 is 10, while the fundamental price of the asset in treatments C3 and L3 is 15. When subjects are intrinsically risk neutral, Proposition 1 implies that the price across all treatments should equal the fundamental price. When all subjects exhibit intrinsic CARA utility, Proposition 3 implies that prices should converge to a value less than 10 in C2 and L2, and to a value less than 15 in C3 and L3. When

[25] We follow the dynamic asset pricing experiment of Camerer and Weigelt (1993) in this regard. This technique for implementing infinite horizon environments in a laboratory setting is quite standard in game theory experiments (e.g., Bó and Fréechette, 2011 and has a rich history, beginning with Roth and Murnighan (1978).

[26] In the instructions, subjects are informed that if the final sequence is not completed within one hour, they would be invited back to the lab as quickly as mutually possible to complete the final sequence. In this event, subjects would be paid immediately for the previous (completed) sequences, but would be paid for the entirety of the final sequence at the conclusion of the follow-up session. Their financial stake in that final sequence is derived from at least 20 periods of play (trading periods are three minutes long), which made the event an unlikely ($\frac{5}{6}^{20} \approx 2.6\%$) but compelling motivator to get subjects back to the lab. As it turns out, we did not have to bring subjects back for any continuation session.

all subjects exhibit intrinsic DARA utility, Proposition 4 implies that prices should converge to the fundamental price in all treatments. To get some sense of the expected speed of convergence, consider homogeneous intrinsic logarithmic utility (the limiting utility as the CRRA preference parameter tends to 1) and homogeneous CRRA induced utility parameter 2.3 (approximately the value used in the experiment).[27] Then the price equation in Proposition 5 implies an equilibrium price equal to 77% of the fundamental price in the first period and 96% of the fundamental price by period 18 (the mean session length in our experiment). So it is not implausible to expect convergence to the fundamental price by the end of the experiment.

3.3 The trading mechanism

General equilibrium models do not specify the actual mechanism by which prices are determined and assets are exchanged. We adopt the double auction mechanism for trade, since it is well known to reliably converge to competitive equilibrium in a wide range of experimental markets. To this end, we use the double auction module in Fischbacher's (2007) z-Tree software.

Prior to the start of each three-minute trading period t, each subject i is informed of her current asset position, k_t^i, and the number of francs she has available for trade, $y_t^i + \overline{\mathrm{D}}k_t^i$. After all subjects click a button confirming they understand their asset and franc allocations, trading begins. Subjects can post buy or sell orders for one unit of the asset at a time. They can sell as many assets as they have available, or buy as many assets as they wish, provided they maintain a balance of at least 11 francs.[28] We institute a standard bid-ask improvement rule: buy offers have to improve on (exceed) existing buy offers and sell offers have to improve on (undercut) existing sell offers to be posted in the (open) limit order book. Subjects can agree to buy or sell at a currently posted price (i.e., submit a market order) by clicking on the Bid/Ask, immediately after which the transaction is executed and the price publicly posted. After a trade, the order book is cleared, but subjects can (and do) immediately begin reposting buy and sell orders. A history of transaction prices and trading volume is always present on subjects' screens. In addition to this information, each subject's franc and asset balances are adjusted in real time in response to any transactions.

3.4 Subjects, payments and timing

Subjects are undergraduate students from the University of Pittsburgh, 18 years of age or older. Subjects could participate in no more than one session of our experiment. There are no other exclusions

[27] For one subject endowment type we induce a value of about 2.2 and for the other type we induce a value of about 2.4

[28] A minimum positive franc balance is implemented because the induced utility of zero francs in the concave treatments is minus infinity. The payoff associated with 11 francs in the concave treatments is −\$9.67 (−\$15.13) for type 1 (2) subjects. Only 2 out of 120 subjects reached this boundary (once each) in the concave treatments, the boundary was reached 31 times (out of more than 2,000 subject-periods) in the linear treatments.

on subject participation. At the beginning of each session, 12 subjects are randomly assigned a role as either a type 1 or type 2 agent, with 6 subjects of each type. Subjects remain in the same role for the duration of the session. They are seated at visually isolated computer workstations and are given written instructions that are also read aloud prior to the start of play in an effort to make the instructions public knowledge. As part of the instructions, each subject is required to complete two quizzes to test comprehension of the induced utility function, the asset market trading rules and other features of the environment. The session does not proceed until all subjects have answered these quiz questions correctly. Instructions (including quizzes, payoff tables, charts and endowment sheets) are reproduced in the Online Appendix. [29] Subjects are recruited for a three hour session, but a typical market ends after a little more than two hours, including instructions (instructions take about 35 minutes). An additional 15 minutes is devoted to the Holt-Laury elicitation task, which is conducted at the end of each session and not announced in advance.

Payoffs are earned from every period of every sequence in the session. Mean (median) payoffs are \$22.65 (\$22.41) per subject in the linear sessions and \$18.75 (\$19.48) in the concave sessions, including a \$5 show-up payment but excluding the payment for the Holt-Laury individual choice experiment.[30] Mean payments are higher in the linear sessions because the sum of individual subject payments are constant across periods. Whereas social welfare is uniquely optimized at the fundamental price equilibrium in the concave sessions.

Following the end of each trading period, t, subject i's franc balance, s_t^i, is determined for that period. The dollar amount of this franc-consumption holding, $\mathrm{u}^i(s_t^i)$, accrues to subject i's cumulative cash earnings from all prior trading periods. This dollar amount is paid at the completion of the session. The timing of events in our experimental design is summarized below:

t	dividends paid; francs=$\overline{\mathrm{D}}k_t^i + y_t^i$, assets=$k_t^i$.	3-minute trading period using a double auction to trade assets and francs.	consumption takes place: $s_t^i = \overline{\mathrm{D}}k_t^i + y_t^i + \sum_j \mathrm{P}_{t,j} \; k_{t,j}^i - k_{t,j-1}^i$.	die roll: continue to $t+1$ w.p. 5/6, else end.	$t+1$

In this timeline, j indexes the transaction completed by subject i in period t. $\mathrm{P}_{t,j}$ is the price governing the jth transaction for i in t. $k_{t,j}^i$ is the number of shares held by i after her j^{th} transaction in period t. In the "autarkic" case where a subject does not transact, $s_t^i = \overline{\mathrm{D}}k_t^i + y_t^i$. In equilibrium, prices faced by all subjects within a period are identical. Under the double auction mechanism, however, they can differ within and across periods and subjects.

[29] Copies of the instructions and materials are available at `http://www.socsci.uci.edu/~duffy/assetpricing/`.

[30] Subjects earned an average of \$7.22 for the subsequent Holt-Laury experiment and this amount was added to subjects' total from the asset pricing experiment.

3.5 Subject risk preferences

Following completion of the last sequence of trading periods, beginning with Session 7 we invite subjects to participate in a further brief experiment involving a single play of the Holt-Laury (2002) paired-lottery choice instrument. This task is commonly used to measure individual risk attitudes, and we collected this data in order to test Hypothesis 5. After the market experiment, subjects are informed that, if they are willing, they can participate in a second experiment that will last an additional 10-15 minutes for which they can earn an additional monetary payment from the set $\{\$0.30, \$4.80, \$6.00, \$11.55\}$.[31] All subjects agreed to participate in this second experiment. The online appendix includes the instructions for the Holt-Laury task.[32]

3.6 Experimental Sessions

We conduct 20 sessions of our market experiment.[33] Each session involves 12 subjects with no prior experience in this design (240 subjects total). The treatments used are summarized in Table 2.

Session	$u^i(s^i)$	$\overline{D}$	Holt-Laury test	Session	$u^i(s^i)$	$\overline{D}$	Holt-Laury test
1	Concave	2	No	11	Concave	3	Yes
2	Concave	3	No	12	Linear	3	Yes
3	Linear	2	No	13	Linear	3	Yes
4	Linear	3	No	14	Concave	3	Yes
5	Linear	2	No	15	Concave	2	Yes
6	Concave	2	No	16	Linear	2	Yes
7	Linear	3	Yes	17	Concave	3	Yes
8	Concave	3	Yes	18	Linear	3	Yes
9	Concave	2	Yes	19	Concave	2	Yes
10	Linear	2	Yes	20	Linear	2	Yes

Table 2: **Assignment of Sessions to Treatment**

We began to administer the Holt-Laury task following completion of the asset pricing experiment in sessions 7 through 20, after it became apparent to us that it might help us to explain the substantial variation in individual behavior that we observed in the linear treatments. Thus, in 14 of our 20 sessions, we have Holt-Laury measures of individual subject's tolerance for risk (168 of our 240 subjects, or 70%).

[31] These payoff amounts are three times those offered by Holt and Laury (2002) in their "low-payoff" treatment. We scale up the possible payoffs to make the amounts comparable to the steady state earnings over an average sequence of trading periods.

[32] The Java script used to carry out the Holt-Laury test may be found at `http://www.socsci.uci.edu/~duffy/assetpricing/`.

[33] We also conduct a follow-up individual choice experiment, as described in Section 5.

4 Experimental findings

We begin by reporting a couple of findings regarding trading volume and market efficiency. First, trading volume is similar across treatments, with mean volume per period around 25 shares in C3 and 23 shares in the other three treatments (the Wilcoxon two-tailed p-value is .529 for pooled linear vs. concave treatments, .222 for C3 vs. C2, and .691 for C3 vs. L3).[34] Second, mean (median) allocative efficiency—earnings as a fraction of the maximum expected payoff at the fundamental price—is 0.73 (0.80) for the concave treatment economies with no difference by dividend payment, while the linear treatment economies are fully efficient by construction. In the next two subsections we report findings related to economies with concave or linear induced utility

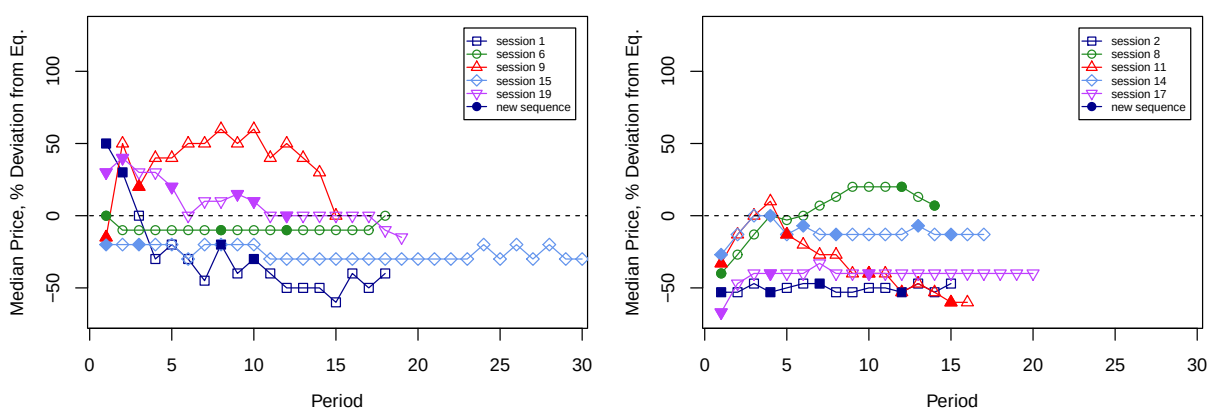
4.1 Findings for induced concave utility

Consistent with Hypothesis 1, we have:

Finding 1. *In the concave utility treatment ($\eta^i < 1$), observed transaction prices at the end of the session are less than or equal to $\overline{\mathrm{P}}^*$ in 9 of 10 sessions.*

To depict this visually, Figure 1 displays median transaction prices by period for the concave sessions, $\overline{\mathrm{D}} = 2$ in Panel A and $\overline{\mathrm{D}} = 3$ in Panel B. Solid dots represent the first period of a new indefinite trading sequence. To facilitate comparisons across sessions, prices are transformed into percentage deviations from the fundamental price $\overline{\mathrm{P}}^*$. For example, a price of -40% in Panel A, where $\overline{\mathrm{D}} = 2$, reflects a price of 6, whereas a price of -40% in Panel B, where $\overline{\mathrm{D}} = 3$, reflects a price of 9.

Figure 1: Equilibrium-normalized Prices, Concave Sessions



(a) Concave $\overline{\mathrm{D}} = 2$ (b) Concave $\overline{\mathrm{D}} = 3$

Of the ten concave utility sessions depicted in Panels A and B of Figure 1, half end relatively close to the asset's fundamental price, with a deviation from this price between -15% and 7%. The other

[34] There is considerably more between-session variation in trading volume in the linear sessions; the standard deviation of volume between linear sessions is 8.0 shares, vs. 2.9 shares in the concave sessions.

half end well below it, with a deviation between -30% and -60%. Several sessions do experience upward pressure on prices above the fundamental price (most notably, sessions 8 and 9), but these "bubbles" are self-correcting by the end of the session.[35] Importantly, these corrections are wholly endogenous, rather than being triggered by a known finite horizon as in SSW. We emphasize that, while prices in the concave treatment lie at or below $\overline{P}^*$, subjects are never informed of this fundamental trading price, as *is* done in some of the SSW-type asset market experiments.

A main implication of consumption-based asset pricing models, as conjectured in Hypothesis 3, is addressed in the next finding.

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

Figure 2: Per Capita Consumption-Smoothing

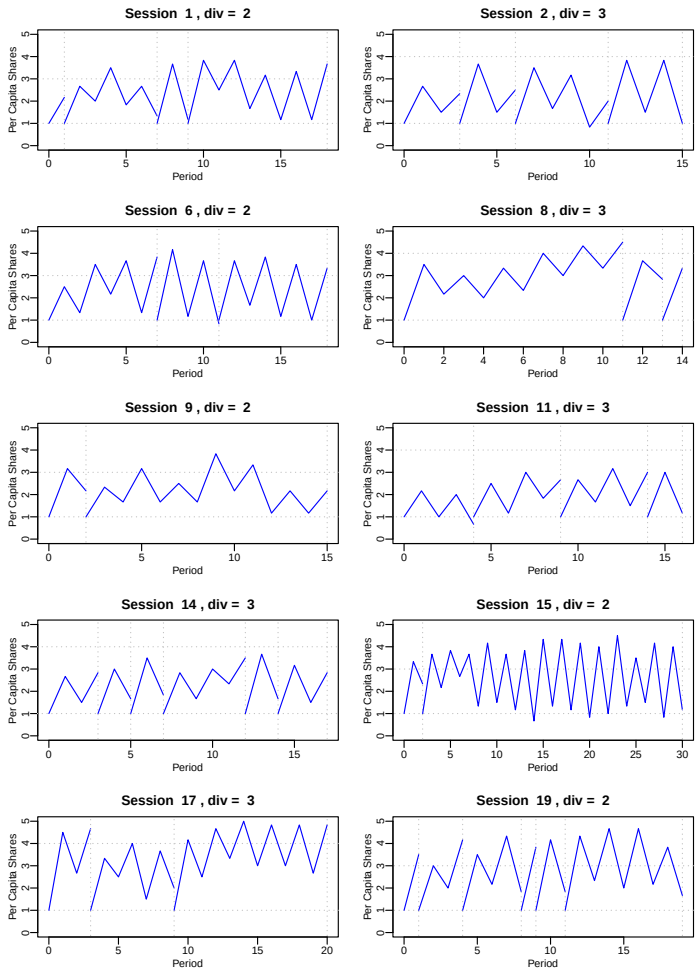


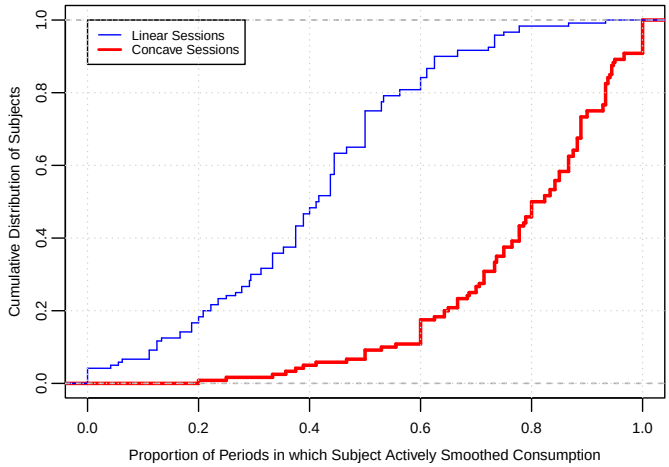
Figure 2 depicts the per capita shareholdings of type 1 subjects by period (per capita shares of type

[35] Formal evidence supporting this statement is presented in the discussion related to Finding 3.

2 subjects is five minus this number). Dashed vertical lines denote the final period of a sequence,[36] and dashed horizontal lines mark fundamental price equilibrium shareholdings (the bottom line for odd periods of a sequence, and the top line for even periods). Recall that equilibrium shareholdings are cyclic, increasing in high income periods and decreasing in low income periods. As Figure 2 indicates, this pattern is precisely what occurred in each and every period on a per capita basis.[37]

Pooling across all concave sessions, on average type 1 subjects (on net) buy 1.94 shares in odd periods (when they have a large endowment of francs) and sell 1.75 shares in even periods (when they have a small endowment). By contrast, in the linear sessions subjects buy only 0.53 mean shares in odd periods and sell 0.25 shares in even periods. Thus, while there is a modest degree of consumption-smoothing in the linear sessions, consumption-smoothing is nearly four times as large in the concave sessions. This indicates that consumption-smoothing observed in Figure 2 is attributed to the concavity of the induced utility function u^i, and *not* to the cyclic income process alone.

Figure 3: Individual Consumption-Smoothing



Consumption-smoothing in the concave induced utility sessions is prevalent across individuals. Figure 3 presents the cumulative distribution, across subjects, of the proportion of periods in which a subject actively smoothes consumption, pooled by induced utility. Half of the subjects in the concave sessions strictly smooth consumption in more than 80% of all trading periods, while less than 2% of subjects in the linear sessions smooth consumption so frequently. Well over 90% of the subjects in the concave sessions smooth consumption in at least half of the periods, whereas only 35% of subjects in the linear sessions smooth consumption so frequently. The difference between these distributions is significant to many digits using a Wilcoxon rank-sum test. Note that the comparative absence of

[36] Thus, there are two allocations associated with each vertical line (except the final line): One for the final allocation of the sequence, and the other for the re-initialized share endowment of the following sequence (always one unit).

[37] In this figure, the period numbers shown are aggregated over all sequences played. From a subject's perspective, each sequence starts with period 1.

consumption-smoothing in the linear sessions is not indicative of anti-consumption smoothing behavior. Rather, it results from the fact that many subjects in the linear treatment do not actively trade any shares in many periods.

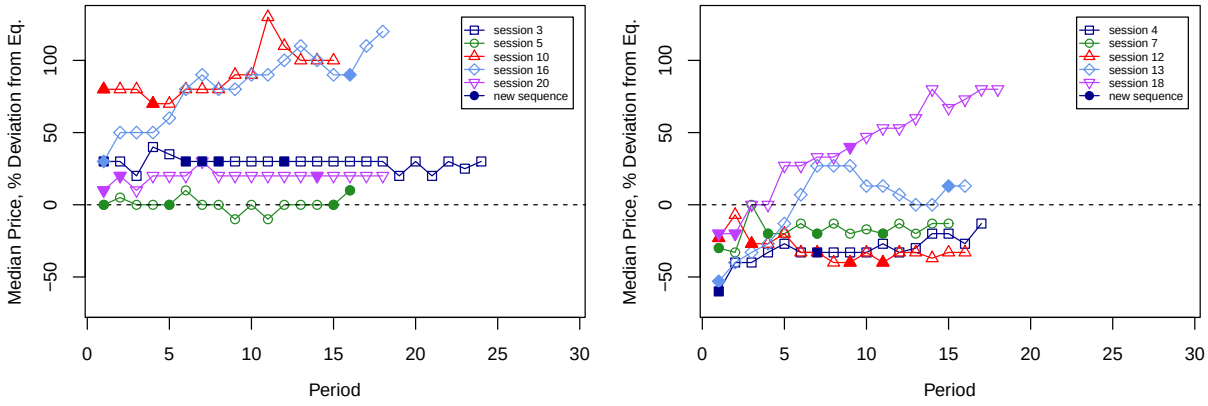
Previous experimental evidence on whether subjects can learn to smooth consumption in an optimal manner without tradeable assets has not been encouraging. By contrast, in our simpler setting, where subjects must engage in trade in the asset in order to smooth consumption, and can observe the transaction prices for that asset in real time, we find strong evidence for consumption-smoothing behavior.

4.2 Findings for induced linear utility

Finding 3. *Transaction prices in the linear utility sessions are significantly higher than transaction prices in the concave utility sessions.*

Figure 4 displays median transaction prices by period for the linear sessions, $\overline{\mathrm{D}} = 2$ in Panel A and $\overline{\mathrm{D}} = 3$ in Panel B. As in Figure 1, solid dots represent the first period of a new indefinite trading sequence, and prices are transformed into percentage deviations from the fundamental price.

Figure 4: Equilibrium-normalized Prices, Linear Sessions



(a) Linear $\overline{\mathrm{D}} = 2$ (b) Linear $\overline{\mathrm{D}} = 3$

Table 3 displays median transaction prices over several frequencies by session, as well as an average of these median prices by treatment (first row, boldface type). Notice that for a given dividend value $\overline{\mathrm{D}} = 2$ or 3, inconsistent with Hypothesis 1 but consistent with the alternative Hypothesis 2, the average treatment price at each frequency is higher in the induced linear utility treatment than in the corresponding induced concave utility treatment. Further, Table 3 reveals the price difference between linear and concave treatments involving the same value of $\overline{\mathrm{D}}$ generally diverges over time: The mean treatment price is monotonically *increasing* in the linear treatments and *decreasing* in the concave treatments. These trends at the session level can be identified using the Mann-Kendall τ

	Median	First Pd	Final Half	Final 5 Pds	Final Pd	τ	p-value
C2-Mean	**9.6**	**10.9**	**9.4**	**9.0**	**8.3**		
S1	7	15	6	5	6	-0.67	0.0002
S6	9	10	9	9	10	0	1
S9	14	8.5	15	14	10	0.02	0.9592
S15	7	8	7	7	7	-0.39	0.0132
S19	11	13	10	10	8.5	-0.80	< 0.0001
L2-Mean	**14.2**	**13.0**	**15.0**	**15.0**	**15.6**		
S3	13	13	13	13	13	-0.32	0.0609
S5	10	10	10	10	11	-0.06	0.8248
S10	18	18	20	20	20	0.63	0.0027
S16	18	13	20	20	22	0.81	< 0.0001
S20	12	11	12	12	12	0.27	0.1946
C3-Mean	**10.8**	**8.4**	**10.8**	**10.6**	**10.4**		
S2	7	7	7	7	8	0.15	0.5174
S8	15	9	17	17	16	0.70	0.0010
S11	10	10	8	7	6	-0.78	< 0.0001
S14	13	11	13	13	13	-0.13	0.5698
S17	9	5	9	9	9	0.28	0.1551
L3-Mean	**13.8**	**9.4**	**15.0**	**15.4**	**16.0**		
S4	10	6	11	12	13	0.72	0.0002
S7	13	10.5	13	13	13	0.33	0.1282
S12	10	11.5	10	10	10	-0.46	0.0228
S13	16	7	17	16	17	0.41	0.0356
S18	20	12	24	26	27	0.95	< 0.0001

Table 3: **Median Transaction Prices By Session and Treatment**

statistic, a non-parametric measure of monotonic trend.[38] The τ values and significance levels are reported in the last two columns of Table 3. Five of ten linear sessions have a significantly positive trends, while only one has a significantly negative trend ($p < .05$). Four of ten concave sessions have a significantly negative trend, while only one has a significantly positive trend ($p < .05$). Thus, of 11 significant trends, 9 are diverging by treatment, increasing the price difference between concave and linear sessions over time. We reject the null hypothesis that the sign of significant trends is drawn from the same binomial distribution in the two induced utility treatments (chi-squared test p-value is .036). This evidence suggests that price differences between the concave and linear sessions would likely have been greater if our experimental sessions had involved more periods of play. We thus look for treatment differences in median prices during the *final* period of each session, as such prices best reflect learning and the long-term trends in these markets, and further, provide the nearest observation to steady state convergence in the event that intrinsic (unobserved) utility is DARA (Proposition 4).

To begin our analysis of price differences by treatment, we first note that, using a Wilcoxon sign-

[38] Here $\tau \in [-1, 1]$, where $\tau = -1$ indicates a strictly monotonic negative trend, $\tau = 1$ a strictly monotonic positive trend, and $\tau = 0$ implies no trend.

rank test, we cannot reject the null hypothesis that final period prices in treatments C2, C3, and L3 are less than or equal to the fundamental price, $\overline{\mathrm{P}}^*$, which was 10, 15 and 15, respectively. However, we can reject the null hypothesis that final period prices in treatment L2 are less than or equal to the fundamental price ($p = .031$).

Next, comparing induced utility treatments for a fixed dividend level, the distribution of final period prices between L2 and C2 is significantly different (Wilcoxon two-tailed p-value is 0.019) but the distribution of final period prices between L3 and C3 is not (p-value is 0.139). Nevertheless, mean differences are quite large in both cases: Pooling data according to the two induced utility treatments alone (for both dividend values) we find that on average, the median final-period price in the induced linear sessions is 32% above the fundamental price, while in the induced concave sessions it is 24% below the fundamental price.[39] The associated pooled Wilcoxon p-value is 0.011, so we reject the null hypothesis that equilibrium-normalized final period prices in the pooled linear sessions are drawn from the same distribution as the concave sessions. Thus, there is strong evidence that the difference in induced utilities caused a strong impact on prices by the end of the session. Prices are considerably greater than the fundamental value in the linear sessions, and considerably lower than the fundamental value in the concave sessions.

Surprisingly, the treatment variation in the dividend value did not induce the predicted impact on prices in the initial periods of our experiment, although it has some impact by the final period, as summarized in Finding 4 and the discussion below.

Finding 4. *For a given induced utility function* u^i*, by the final period, mean prices are higher in sessions with higher dividend payments,* $\overline{\mathrm{D}}$*.*

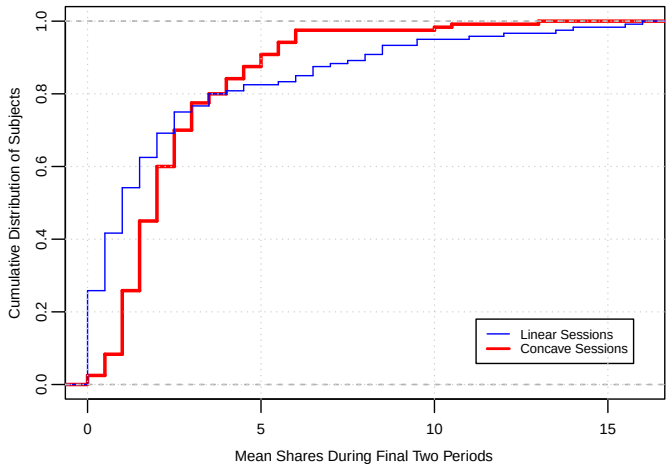
Consistent with Hypothesis 4, Table 3 reveals that the mean of final period prices across the five sessions of C2 is 8.3, relative to 10.4 in C3. The mean final price in L2 is 15.6 relative to a mean final price of 16 in L3. Thus, by the end of the experiment, prices indeed tended to be greater when $\overline{\mathrm{D}} = 3$ than when $\overline{\mathrm{D}} = 2$ (though smaller when normalized as a percentage change from the fundamental price). However, this result is not statistically significant.

We note that this result is initially reversed. As Table 3 reveals, the mean first period price in C2 is 10.9 relative to 8.4 in C3, and the mean first period price in L2 is 13.0 relative to 9.4 in L3. In fact, normalizing prices to be expressed as a fraction of the fundamental price, every session in C2 (L2) initializes at a higher normalized price than every session in C3 (L3), which is statistically significant. This difference in initial conditions may be a consequence of higher (lower) franc balances relative to the fundamental value of the asset in the low (high) dividend treatments[40] or it could simply take

[39] We justify pooling by the two induced utility treatments because the distributions of final period prices in C2 vs. C3 and L2 vs. L3 are not significantly different from each other at the 5% level (p-values of 0.172 and 0.094, respectively).

[40] The total value of the fixed stock of 30 shares at the fundamental price when $\overline{\mathrm{D}} = 3$ is $30 \times 15 = 450$ francs per period

Figure 5: Distribution (by Treatment) of Mean Shareholdings During the Final Two Periods



some time for subjects to develop an appreciation for the relationship between the dividend and asset values.

Thus, dividend has an unexpectedly negative (though relatively small) impact on prices in the first period, when the induced utility function u^i appears to have little impact on prices. However, by the end of the session, mean (non-normalized) prices are higher for $\overline{D} = 3$ than for $\overline{D} = 2$, within each induced utility condition. Therefore, by the end of the experiment, induced utility is the main determinant of price differences, and on average, variation in the dividend level has the expected comparative static impact.

Finding 5. *In the linear induced utility treatment, the asset is "hoarded" by just a few subjects.*

In the linear utility sessions, where there is no clear motivation to engage in trade in the asset, markets are nevertheless active. Nearly half of the subjects ultimately sell all of their shares, and a small number of subjects accumulate most of the shares. Figure 5 displays the cumulative distribution of mean individual shareholdings during the final two periods of the final sequence of each session, pooled according to the induced utility function. [41] We average across two periods to account for consumption-smoothing. We focus on final shareholdings because it can take several periods within a sequence for a subject to achieve a targeted position due to the budget constraint. Forty-two percent of subjects in the linear sessions hold an average of 0.5 shares or less during the final two periods. By contrast, just 8% of subjects in the concave sessions hold so few shares. At the other extreme, 17% of

(number of shares times the value of each share at the fundamental price), while the total value of the 30 shares when $\overline{D} = 2$ is $30 \times 10 = 300$ francs. The total quantity of francs available per period when $\overline{D} = 3$ is $134 \times 6 + 30 \times 3 = 894$ francs (income per subject pair times 6 pairs plus total shares times dividend), while the quantity when $\overline{D} = 2$ is $134 \times 6 + 30 \times 2 = 864$. So the value of shares as a percentage of total resources per period is about 50% when $\overline{D} = 3$ but only 34% when $\overline{D} = 2$. Caginalp, Porter, and Smith (1998), among others, report that increasing francs relative to a fixed total (fundamental) value increases asset prices in the SSW setting. Thus, it is possible than an analogous effect happens in our design, resulting in the initial miss-pricing.

[41] We use the final sequence with a duration of at least two periods.

subjects in the linear sessions average at least 6 shares during the final two periods, while only 6% of subjects in the concave sessions hold so many.

The inequality in the distribution of shareholdings can be measured by the Gini coefficient, which is equal to zero when each subject holds an identical quantity of shares and is equal to one when a single subject owns all shares. Across all treatments, in autarky the Gini coefficient is 0.3. This is also the value of the Gini coefficient over the final two periods of the fundamental price equilibrium in treatment C2. In C3, the Gini coefficient is slightly lower (0.25). The mean Gini coefficient for mean shareholdings in the final two periods of all concave sessions is 0.37, not so far from the equilibrium values. By contrast, the Gini coefficient in the pooled linear sessions is significantly larger, at 0.64 (statistically significant to many significant digits). This difference reflects the "hoarding" of a large number of shares by just a few subjects in the linear sessions, behavior that is absent in the concave sessions.[42]

4.3 Findings for intrinsic risk preferences

Our hypotheses imply that, when subjects are intrinsically risk neutral, the observed price should be $\overline{\mathrm{P}}^*$ in all treatments. Further, when subjects are characterized by strict DARA intrinsic utility, observed prices should converge to $\overline{\mathrm{P}}^*$ in all treatments. Finally, when subjects are characterized by CARA intrinsic utility, observed prices should be less than $\overline{\mathrm{P}}^*$. Beginning with our seventh experimental session, we ask subjects to participate in a second experiment involving the Holt and Laury (2002) paired lottery choice risk elicitation task. This second experiment takes place *after* the conclusion of the asset market experiment, and is *not* announced in advance to minimize any potential influence on decisions in the asset market.

In this second experiment, which takes about 5 minutes to complete, subjects face a series of 10 choices between binary lotteries A and B. The payments of lottery A are \$6 and \$4.80, and those of lottery B are \$11.55 and \$0.30. For each choice $j \in \{1, 2, ..10\}$, the probability of getting the high payoff in either lottery is $\frac{1}{10}j$. One of the ten choices is selected at random, with the chosen lottery played for payment. As detailed in Holt and Laury, a risk-neutral expected utility maximizer should choose B—the high-variance lottery—6 times. We define a subject's *HL score* as the number of times the subject selects the riskier lottery B. HL scores lower (greater) than 6 indicate risk averse (risk seeking) behavior. In our sessions, the mean HL score is 3.87 with a standard deviation of 1.81, indicating moderate overall risk aversion; indeed, 83.3 percent of subjects are classified as risk averse, 10.1 percent as risk neutral and the remaining 6.6 percent as risk-seeking, a fairly typical distribution.

[42] Interestingly, exactly two of twelve subjects in each of the ten linear sessions hold an average of at least 6 shares of the asset during the final two trading periods. Recall that the aggregate endowment in all sessions is 30 shares. Thus, the subjects in the right tail of the distribution in Figure 5 are divided up evenly across the ten linear sessions.

To compare behavior in linear versus concave induced utility treatments, we regress (using OLS) a subject's mean shareholdings during the final two periods on the subject's HL score, with session fixed effects and robust standard errors clustered on session-level observations. In the linear case, the estimated coefficient on the HL score is 0.65 with p-value 0.0181 (Table B.1). Thus, a one standard deviation increase in the HL score (equal to 1.8 additional high-variance choices) implies a subject is expected to hold nearly 1.2 additional shares of the asset by the end of the session. This is a large impact, as there are only 2.5 shares per capita in these economies.[43] We further note that the median HL score of the largest shareholder per linear session is 6, and the median HL score of the two largest shareholders per session is 5. The mean HL score of these 14 subjects (7 sessions) is 5.125, relative to a mean of 3.869 across all subjects.

On the other hand, in the concave case, the estimated coefficient is -0.16 with (cluster-robust) p-value 0.137 (Table B.3), a statistically insignificant and small impact. Thus, the HL score is a far more useful predictor of final shareholdings in the linear sessions. This result for linear induced utility is consistent with Breaban and Noussair (2015), who report that subjects with higher HL scores tend to hold more assets in a SSW-related experiment.

Finding 6. *Risk-tolerant subjects tend to hold significantly more shares of the asset in the linear treatment sessions, but not in the concave treatment sessions.*

Finally, we test Hypothesis 5, that sessions with higher HL scores trade at higher prices in both the concave and linear treatments. We report the relation between the mean HL score and median final period price at the session level. What follows is robust to many other summary statistics for the distribution of HL scores, such as the median, upper quartile, etc. Following Taylor (1987), we use treatment as a blocking variable and calculate the weighted average Spearman's Rho—a non-parametric measure of correlation—across treatments, assuming that ρ_i and ρ_j are independent for any pair of treatments i and j. Letting n_i be the number of sessions in treatment i, the weighted average $\rho = \frac{\rho_i(n_i-1)}{(n_i-1)} = -0.12$. The statistic $\rho\sqrt{\quad(n_i-1)} = -0.3795$ is a draw from a standard normal distribution, with associated p-value of 0.7044. Thus, the null hypothesis of a significant relation between HL scores and price is rejected. Similarly, the test statistics are also quite small for both the linear and concave treatments alone.

Finding 7. *We do not identify a significant statistical relation between mean HL score and final period median price at the session level.*

[43] Since the distribution of HL scores within-session is endogenous, for additional robustness, we also regress each subject's share of the sum of HL scores within-session on her average final shareholdings. The coefficient is 39.81 with p-value 0.0001 (Table B.2). Playing against the observed frequency of HL scores (across all sessions) for the other eleven subjects in each session, a risk-neutral subject with an HL score of 6 is predicted to hold 0.74 shares more than a subject with a score of 5, even larger than the prediction obtained using the raw score approach.

Ex-post, this finding is not so surprising. Prices in the linear treatment sessions are typically greater than the equilibrium price bounds identified in Section 2.3, and Hypothesis 5 is derived under the assumption of equilibrium behavior. Further, concentrated asset holdings in the linear treatment (Finding 5) weakens the likelihood that a central measure of HL scores correlates with prices. In the concave treatment sessions, the strength of the induced preference parameters implies that the difference between the optimal savings path and perfect consumption-smoothing (under which the market mechanically clears when everyone smoothes) is relatively small for a wide range of prices. Consider, for example, an intrinsically risk-neutral subject in treatment C3 who faces a constant price of 6 (relative to a fundamental price of 15). By Equation (17), she should increase her savings by about 10% per period. In this treatment, an intrinsically risk-averse subject should increase their savings by less (or not at all). Thus, the salience of Hypothesis 5 is modest, as excess demand off the equilibrium path is expected to be small.

As noted above, we conduct the Holt-Laury test only *after* the market experiment concludes, as the market is the main focus of our study. However, this order of tasks may affect outcomes in the Holt-Laury risk elicitation. To rule this out, we regress individuals' HL scores on treatment dummy variables ('linear' or 'D3'), and on the individuals' earnings from the first part of our experiment (asset market). The OLS regression findings, with robust standard errors clustered on session-level observations as reported in Table B.4, indicate that neither treatment variables nor subjects' earnings are statistically significant factors in explaining HL scores across sessions. This is reassuring evidence that the HL scores, elicited following the asset pricing part of the experiment, are not affected by asset market conditions or payoff outcomes.

4.4 Discussion of high prices in the induced linear utility sessions

Market behavior for the induced concave utility treatment is consistent with our hypotheses: Final prices are at or below $\overline{P}^*$, there is widespread consumption-smoothing, and a higher dividend leads to higher final prices. By contrast, in the induced linear utility treatment, we observe final prices that are greater than $\overline{P}^*$ in 7 out of 10 sessions, contradicting Hypothesis 1 but consistent with the bubble prices reported by SSW (Hypothesis 2) that motivated our experiment. We briefly consider several rationalizations for these differences, before turning to an explicating experiment.

Risk-seeking behavior. Since more risk-tolerant subjects tend to hold more shares in the induced linear utility sessions (Finding 6), a possible explanation for the high prices in that treatment is that risk-seeking subjects drive prices above $\overline{P}^*$. In total, we conduct seven induced linear utility sessions for which we have HL scores. Three of these sessions have no risk-seeking subjects present, yet each of these sessions end at a median price above $\overline{P}^*$. One of the seven sessions has three risk-seeking

subjects, yet the price in this session remains considerably lower than $\overline{\mathrm{P}}^*$ in every period of the session. Of the remaining three sessions, with one risk-seeking subject each, two conclude at a median final period price above $\overline{\mathrm{P}}^*$, and one ends below. Of the two high-price sessions, in one of them the risk-seeking subject ends the session with 3 shares, and averages holding 1.4 shares per period. In the other, the risk-seeking subject ends the session holding 15 shares, and averages holding 7.8 shares per period. Thus, we observe high prices being driven by a subject identified as risk-seeking in only 1 of 7 sessions. It would appear that risk-seeking preferences alone, as identified by the HL score, is insufficient to explain the high prices we observe in the linear induced utility sessions.

Probability weighting. Kahneman and Tversky (1979) propose that, while making decisions, individuals tend to act as if they distort probabilities through a probability weighting function. Subsequent studies (e.g., Tversky and Kahneman (1992), Camerer and Ho (1994)) show that the median individual tends to underweight high probabilities and overweight low probabilities. In our experiment, such distortions would tend to lower prices rather than raise them, as the continuation (termination) probability would tend to be perceived as less than (greater than) 5/6 (1/6). Other studies (e.g., Birnbaum and McIntosh (1996), Etchart (2009), and Kemel and Travers (2016)) have shown that individuals tend to overweight the probabilities of low outcomes (low future prices) and underweight the probabilities of high outcomes (high future prices). Again, such distortions (pessimism) would tend to lower prices rather than raise them.

However, as emphasized by Gonzalez and Wu (1999), there is substantial heterogeneity in these distortions. For simplicity, consider a subject i with both linear u^i and U^i, but a probability weighting function $w^i(\pi)$. Clearly, the subject should buy as many shares of the asset as possible for a constant price less than $\frac{\overline{\mathrm{D}}w^i(\pi)}{1-w^i(\pi)}$, and sell for a constant price greater than $\frac{\overline{\mathrm{D}}w^i(\pi)}{1-w^i(\pi)}$. Thus, it only takes one of twelve subjects with $w^i\left(\frac{5}{6}\right) > \frac{5}{6}$ (i.e., subject i overweights π) to support prices greater than $\overline{\mathrm{P}}^*$. While we might expect some relation between subject i's HL score and $w^i\left(\frac{5}{6}\right)$, this relation need not be monotonic across subjects.

Speculative trading. If a subject believes prices will increase over time, a strategy of purchasing shares in the current period and selling them in a future period may be rationalizable even if the current price is greater than $\overline{\mathrm{P}}^*$. As previously mentioned in section 2.4, Scheinkman and Xiong (2003) and Hong et al. (2006) develop models in which optimistic or overconfident investors can push equilibrium prices beyond fundamentals. As we did not elicit beliefs, we do not bring evidence to bear on this hypothesis, but we do note Haruvy et al. (2007) provide evidence of overly optimistic beliefs about prices in the standard SSW design.

5 Eliminating trading uncertainty

Individuals in our market experiment face two sources of uncertainty: (i) about the horizon length and (ii) about trading opportunities (i.e., prices and liquidity). To focus on the former, we conduct an additional set of experimental sessions in which we eliminate trading uncertainty by allowing individual subjects to buy and sell an unlimited number of shares of the asset at an exogenously fixed price.[44] We refer to this experiment as the *individual choice* experiment, and to the previous experiment as the *market choice* experiment.

In this new individual choice experiment, we adhere to our market choice framework as closely as possible. We again set $\pi = \frac{5}{6}$ and assign all subjects the Type 1 endowments and 2-cycle income process. [45] We induce the Type 1 utility functions, concave or linear u, from the market experiment as one treatment variable. Each subject's decisions have no spillover effects onto other subjects, and are restricted only by her own budget constraint. We fixed the dividend on the asset to $\overline{\mathrm{D}} = 2$, so the risk-neutral fundamental price of the asset in *all* of these individual choice sessions is $\overline{\mathrm{P}}^* = 10$. A second treatment variable is the fixed price at which subjects can buy or sell the asset, $\overline{\mathrm{P}} \in \{7, 10, 13\}$. Subjects with induced concave utility either face a price of 7 or 10 for the entire experiment, which we refer to as treatments C2-7 and C2-10, respectively. Subjects with induced linear utility either face a price of 10 or 13 for the entire experiment, which we refer to as treatments L2-10 and L2-13.[46] Both risk preferences and probability weighting may impact on behavior in this individual choice experiment.[47] However, there is no scope for speculation to play a role in the individual choice experiment, as subjects face no uncertainty with respect to price or liquidity in these experiments.

In the individual choice sessions, subjects are asked to enter a desired quantity of shares in a text box and choose whether to "Buy" or "Sell" that number of shares. Subjects who wish to maintain their share position in the current period are instructed to enter "0" in the text entry box and click either "Buy" or "Sell." Thus, the effort to hold a position was equal to the effort to buy or sell shares.

Table 4 summarizes the treatments of this individual choice experiment, which involves six experimental sessions with 12 subjects per session split equally between two treatments. (72 subjects in total).[48] We have thus have 18 independent observations for each of the four individual choice

[44] We thank an anonymous referee for suggesting this treatment.

[45] As prices are exogenous in our individual choice experiment, there is no longer any need to have two player types.

[46] Recall that mean prices in the concave market choice sessions average 24% below $\overline{\mathrm{P}}^*$, while mean prices in the linear market choice experiments average 32% above $\overline{\mathrm{P}}^*$. The two non-fundamental price treatments, (prices of 7 in the concave treatment (C2-7) or 13 in the linear treatment (L2-13) thus reflect the mean deviations we found in the market choice experiment.

[47] Regarding the impact of probability weighting, consider a risk-neutral subject for whom $w^i(\pi = 5/6) = \frac{7}{8}$. This subject will value one unit of the asset at 14 francs when $\overline{\mathrm{D}} = 2$ (as opposed to the unweighted price of 10 francs). Thus, when facing a fixed price of 13 francs, this subject should optimally purchase as many shares as her budget constraint allows.

[48] The subjects in these individual choice sessions are University of Pittsburgh undergraduates who did not previously

Session	u (s)	$\overline{\mathrm{D}}$	Prices (# Subjects)	
17	Concave	2	7 (6)	10 (6)
18	Concave	2	7 (6)	10 (6)
19	Concave	2	7 (6)	10 (6)
17-19	Concave	2	7 (18)	10 (18)
20	Linear	2	10 (6)	13 (6)
21	Linear	2	10 (6)	13 (6)
22	Linear	2	10 (6)	13 (6)
20-22	Linear	2	10 (18)	13 (18)

Table 4: **Individual choice sessions**

treatments C2-7, C2-10, L2-10 and L2-13. At the end of these sessions, subjects are again asked to complete a Holt-Laury risk preference elicitation.[49]

5.1 Consumption smoothing

We first consider the proportion of periods that a subject buys (sells) shares in high (low) income periods. The distributions of these proportions across subjects are significantly different (to many significant digits) between the pooled linear and concave individual choice treatments. The difference in consumption-smoothing between the linear individual choice and linear market treatments is insignificant (p-value 0.88), while the difference between the concave individual choice and concave market treatments is significant (p-value 0.001); subjects smooth consumption even more frequently in the concave individual choice treatments. In fact, nearly half of subjects smooth their consumption in every period.

The standard deviation of consumption relative to autarky across periods provides additional evidence for strong consumption smoothing in the concave individual choice treatment.[50] Pooling subjects into linear and concave treatments, this statistic is significantly different from autarky in both cases, but in *opposite* directions. In fact, only 3 of 36 subjects have a standard deviation of consumption greater than autarky in the concave treatments, while only 5 of 36 subjects have a standard deviation of consumption less than autarky in the linear treatments.

Finding 8. *The extent of consumption smoothing is significantly greater in the concave individual choice setting than in the concave market choice setting, which we attribute to the price certainty of the individual choice setting. Eliminating price uncertainty has no effect on the extent of consumption smoothing in the linear utility setting, where it continues to be far less than in the concave treatment.*

participate in any of our market choice experiments.

[49] The instructions we use in these sessions are reported in the Online Appendix.

[50] The means of these ratios are 1.58 and 1.33 in L2-10 and L2-13, and 0.52 and 0.57 in C2-10 and C2-7, respectively.

5.2 Trading volume

In the concave individual choice treatment with a fixed price of 10, (C2-10), the mean decision is to sell 2 shares in even (low-income) periods and to buy 2.5 shares in odd (high-income) periods. In the concave treatment with a fixed price of 7, (C2-7), the mean decision in even periods is to sell 2.7 shares, and the mean decision in odd periods is to buy 3.4 shares. Perfect consumption smoothing requires buying (selling) 3 shares in high (low) income periods of treatment C2-10 and 4 shares in treatment C2-7. Thus, mean trading volume is within one share of perfect consumption-smoothing in both treatments. Consistent with Equation (25), while the overwhelming tendency in both concave treatments is to smooth consumption, the volume of trade is substantially larger when the price is 7 rather than 10. In both odd and even periods, the distribution of choices in C2-10 vs. C2-7 are significantly different from each other, with Wilcoxon p-values less than 0.01.

Finding 9. *Trading volume is significantly larger with a fixed price of 7 as compared with a fixed price of 10 in the concave treatments, with the mean extent of consumption smoothing between treatments roughly constant.*

In the linear sessions, $\frac{\mathrm{u}^{i\prime}(s_{t+1})}{\mathrm{u}^{i\prime}(s_t)} = 1$. Given a constant price $\overline{\mathrm{P}}$, dividend $\overline{\mathrm{D}}$, and our maintained assumption that $\beta = 1$, Equation (17) can be rearranged as $\frac{\mathrm{U}^{i\prime}(\zeta_{t+1})}{\mathrm{U}^{i\prime}(\zeta_t)} = \frac{\overline{\mathrm{P}}}{\pi(\overline{\mathrm{P}}+\overline{\mathrm{D}})}$. For an intrinsically risk-averse subject facing $\overline{\mathrm{P}} \geq \overline{\mathrm{P}}^*$ as in our treatments L2-10 and L2-13, this expression implies that $\frac{\mathrm{U}^{i\prime}(\zeta_{t+1})}{\mathrm{U}^{i\prime}(\zeta_t)} \geq 1$, which is infeasible since short sales are not permitted (recall that $\zeta_{t+1} = \zeta_t + c_{t+1}$). Therefore, such intrinsically risk-averse subjects should sell all of their shares in the first possible instance so as to maximize their current consumption. However, few of our subjects "cash out" as predicted; in fact, only 5 of 33 subjects (15%) are even close to the prediction that a subject who is strictly risk averse in L2-10 or weakly risk averse in L2-13 will sell all of her shares in the first period and hold no shares throughout the experiment.[51] However, mean trading volume at the higher price is nearly cut in half, from 3.9 shares per period when the price is 10 to just 1.7 shares when the price is 13.[52]

Finding 10. *In the linear treatments, mean trading volume is more than double for a price of 10 relative to a price of 13, comparative statics which are consistent with expected utility theory reasoning. However, only a few subjects (15%) individually behave in a manner even loosely consistent with "cashing out" as predicted by their HL score under expected utility theory.*

[51] We conservatively define a "near cash out" criteria as: (1) Holding fewer than one share on average in the final two periods, (2) Ending at least one-third of all periods with zero shares, and (3) Holding less than two shares per period on average throughout the session. Only 2 of 33 subjects actually held zero shares throughout the experiment as predicted.

[52] Nearly one-third of all trades involve more than 5 shares of the asset in L2-10, while just over 10% of trades involve more than 3 shares in L2-13.

5.3 Intrinsic risk aversion

To examine the relation between shareholdings and Holt-Laury scores, we consider mean shareholdings during the final two periods as we did in the market choice experiment. Recall that in the pooled linear market choice experiments, 42% of subjects hold less than one share during the final two periods, while 16% hold at least 6 shares. By comparison in L2-13 (L2-10), 44% (17%) of subjects hold less than one share during the final two periods, while 11% (28%) hold six or more. Thus, at the high price, subjects in the linear individual choice experiment are far more likely to cash out and less likely to hold a large number of shares.

Consistent with the market choice experiment, the relation between HL score and final shareholdings in both concave individual choice treatments is insignificant according to an OLS regression. Also consistent with the market choice experiment, in the linear individual choice treatment, the impact of HL score on final shareholdings in treatment L2-10 is positive and statistically significant.[53] However, in the linear individual choice treatment L2-13, the relation between HL score and final shareholdings is statistically insignificant; in fact, the estimated coefficient is negative (see Table B.6). This unexpected finding suggests a re-investigation of the market choice experiment data.

We partition the linear market choice sessions for which we have HL scores into those with an average price in the final two periods at least 30% greater than the fundamental value, and sessions with a lower price.[54] For the low-price group, the relation between HL score and final shares is positive but insignificant (the estimated coefficient is 0.39 with p-value 0.1131), while for the high-price group the relation is positive and significant (the estimated coefficient is 0.81 with p-value 0.0142). The results are reported in Tables B.7 and B.8.[55] Thus, HL scores are predictive of shareholdings for high but not low prices in the linear market choice sessions, and for low but not high prices in the linear individual choice sessions.

To develop some insight into what drives this difference, we consider shareholdings for three HL score clusters (risk averse, approximately risk neutral, and risk seeking), subdivided into low- and high-price sessions. Table 5 displays average final shares. Subjects generally purchase fewer shares under high prices **except** the risk-neutral group in a market choice setting, who on average purchase far more shares. While there is no significant difference between the distribution of shareholdings for the risk-neutral group versus other subjects when prices are low (Wilcoxon p-value 0.9901), in the

[53] The coefficient on HL score is large, 0.93, with associated p-value of 0.0337. Full results are reported in Table B.5.

[54] This partition has several useful properties: (1) Thirty percent represents the high-price designation in the individual choice experiment; (2) Thirty percent separates the market choice treatment sessions into two relatively equal-sized groups; and (3) There is a distinct break in prices between the two groups; the low-price group concludes at prices of -33%, -13%, 13%, and 20%, while the high-price group finishes at 80%, 100% and 115%.

[55] Adjusting for HL score heterogeneity between sessions by regressing a subject's share of the total HL score within-session on final shareholdings confirms this result. The slope coefficient is 21 with a p-value of 0.124 in the low-price case, while the coefficient is 53 with a p-value of 0.0026 in the high-price case.

market choice sessions there is a significant difference when prices are high (p-value 0.0022).

		Final Shareholdings by HL Score		
Treatment	**Price**	**HL 1-4**	**HL 5-7**	**HL 8-10**
Market	Low	2.19	3.01	3.83
Market	High	1.13	5.13	2.5
Choice	Low	3.14	5.13	NaN
Choice	High	2.07	2.17	NaN

Table 5: **Mean Final Shares in Linear Individual Choice Sessions**

Finding 11. *The distribution of final shareholdings in the individual choice sessions appears to be relatively consistent with shareholdings in the market choice sessions for both concave and linear induced utility. However, while subjects tend to hold fewer shares in the linear individual choice sessions when the price is high, in the linear market choice sessions, subjects who are approximately risk neutral according to the Holt-Laury elicitation substantially increase their shareholdings.*

In the linear individual choice experiment, high prices cause subjects to purchase fewer shares. However, in the linear market choice experiment one group of subjects increases its demand for shares at far greater prices: the group of subjects identified as approximately risk neutral by the Holt-Laury elicitation. Thus, **speculation** about the likelihood of future price increases may play a more substantial role than **risk-seeking** behavior or **probability weighting** in causing the large price bubbles we observe in the linear market choice experiment. But why are the approximately risk-neutral subjects the ones who bid up assets prices? Here, we must ourselves become speculative, and point to the existing literature for some possible clues.

De Martino et al. (2013) report an increased propensity to "ride" financial bubbles in a SSW setting for individuals whose economic value computations are affected by social signals. Their interpretation is that individuals who incorporate inferences about the intentions of others when making financial decisions are the most likely to bid asset prices above fundamentals, fueling a bubble. They stress that these results "suggest that during financial bubbles, participants' choices are less driven by explicit information available in the market (i.e., prices and fundamentals) and are more driven by other computational processes, perhaps imagining the path of future prices and likely the behavior of other traders" (p. 1223). That is, individuals with a strong theory of mind (ToM) suffer "enhanced susceptibility to buying assets at prices exceeding their fundamental value" (p. 1223).

Ibanez et al. (2013) establish a strong relation between fluid intelligence and ToM, while Benjamin et al. (2013) establish a relation between cognitive ability and small-stakes risk neutrality. Assuming that the associated correlations aggregate so that small-stakes risk neutrality is associated with higher ToM, approximately risk-neutral subjects may bid up asset prices in our linear market choice exper-

iment, but demand fewer shares in our individual choice experiment at high prices, because in the individual choice experiment there are no intentions of "others" to predict, and thus no speculative rewards.

6 Conclusion

The consumption-based asset pricing model is a workhorse framework that continues to be used in macroeconomics and finance, despite weak empirical support using non-experimental field data. In this paper, we develop and test an implementation of the comparative static predictions of consumption-based asset pricing models in the controlled conditions of the laboratory which allows for more careful control over the environment and data measurement than is possible using field data. Thus, one aim of this paper is to provide a test of consumption-based asset pricing models under highly favorable conditions, abstracting from noisy potential confounds. A second aim of this paper is to build a bridge between the experimental asset pricing literature, which has typically followed the SSW experimental design, and the consumption-based asset pricing models used in the macro finance literature.

We find that the consumption-based asset pricing model performs well in some dimensions. In particular, we find strong evidence in our concave induced utility treatment that subjects use the asset to intertemporally smooth their consumption by buying shares in high-income periods and selling shares in low-income periods. Further, we find that prices respond to changes in economic fundamentals, e.g., to changes in the dividend the asset pays. Finally, we are able to rationalize the prices we observe, mostly at or below the fundamental price, by accounting for subjects' intrinsic risk aversion. This latter finding is new to the literature and would be hard to obtain outside of the laboratory.

For comparison purposes, we also implement a linear induced utility market treatment that is closer to the SSW design in the sense that subjects are not exogenously motivated to use the asset to smooth consumption or to engage in any trade whatsoever. In this treatment, we find that asset prices are considerably higher than in the comparable concave induced utility treatment. Six of our ten linear utility economies experience sustained deviations above the fundamental price, and in five of those sessions the "bubble" exhibits no sign of collapse. By contrast, when consumption-smoothing is induced in an otherwise identical economy, as in our concave treatment, such price bubbles are less frequent, of lower magnitude, and of shorter duration. Thus, one main take-away from our experiment for macroeconomic and finance researchers is that concavity of the utility function is not only necessary for consumption smoothing; it is also essential to prevent asset price bubbles from arising.

Indeed, in a follow-up individual choice experiment, we infer that speculation rather than risk-seeking behavior or probability weighting is the most likely cause of bubbles in the linear market

choice experiment. Subjects identified as approximately risk neutral according to the Holt-Laury paired choice task are the primary buyers of assets during linear market bubbles, but these same subjects buy comparatively fewer shares at a constant price above fundamentals in the individual choice experiment, where speculation is not possible.

Our research can be extended in at least three distinct directions. First, the experimental design can be moved a step closer to the environments used in the macrofinance literature by adding a Markov process for dividends and/or a known, constant growth rate in endowment income. Such treatments would allow for the exploration of the robustness of our present findings to stochastic or growing environments. Further, the design could be extended to induce consumption-smoothing through overlapping generations rather than cyclic income and concave induced utility.

Second, it could be useful to combine various elements of our design with the much-studied experimental design of Smith et al. (1988) to further explore reasons for the observed differences in behavior under our design versus the design of SSW. For example, one could add a constant continuation probability to the finite horizon, linear (induced) utility design of SSW. Would the interaction of a finite horizon with random termination inhibit bubbles relative to the SSW design? Or is an induced economic incentive to trade necessary to prevent a small group of speculators from effectively setting prices across a broad range of economies?

Finally, our approach suggests that heterogeneity in individual characteristics, namely preferences for risk as identified by the paired choice lottery task, plays a role in the determination of asset prices, particularly in the extent of the departures of asset prices from fundamentals. However, this impact appears not to be driven by a mechanical application of expected utility theory, but rather a correlation between proximity to risk neutrality and the likelihood to engage in speculative activity. Theoretical work which pairs risk attitudes with belief distributions that support speculative behavior may prove useful to explain the mechanics of asset price bubbles.

We leave these extensions and additional experimental designs to future research.

Appendices

A Proofs

Lemma 1. *The equilibrium solution to the maximization problem, defined in Equation* (12)*, satisfies*

$$\mathrm{v}^{i\prime}\left(m_t^i\right) = (1-\pi)\,\mathrm{U}^{i\prime}\left(\zeta_t^i\right)\mathrm{u}^{i\prime}\left(s_t^i\right). \tag{26}$$

Proof. Drop the superscript i and write s_t^* as a function $s_t^*(m_t)$ of m_t, such that the solution s_t^* depends on m_t. That is, $s_t^*(m_t)$ is a function that solves the maximization problem in Equation (12) for any given m_t. Define the function

$$f\left(m_t, s_t^*(m_t)\right) = (1-\pi)\,\mathrm{U}(\zeta_t) + \pi\beta\mathbb{E}_t\left[\mathrm{v}(m_{t+1})\right]. \tag{27}$$

By the Envelope Theorem (e.g., Milgrom and Segal (2002)), the total derivative of f is

$$\frac{df}{dm_t} = \frac{\partial f}{\partial m_t} + \frac{\partial f}{\partial s_t}\frac{ds_t^*}{dm_t}. \tag{28}$$

Since k_{t+1} can be written $k_{t+1} = \frac{1}{\mathrm{P}_t}(m_t + y_t - s_t)$,

$$m_{t+1} = \frac{\mathrm{P}_{t+1} + \mathrm{D}_{t+1}}{\mathrm{P}_t}(m_t + y_t - s_t). \tag{29}$$

Thus,

$$\frac{\partial f}{\partial m_t} = \pi\beta\mathbb{E}_t\left[\mathrm{v}'(m_{t+1})\frac{\mathrm{P}_{t+1} + \mathrm{D}_{t+1}}{\mathrm{P}_t}\right]. \tag{30}$$

Differentiating f with respect to s_t gives

$$\frac{\partial f}{\partial s_t} = (1-\pi)\,\mathrm{U}'(\zeta_t)\,\mathrm{u}'(s_t) - \pi\beta\mathbb{E}_t\left[\mathrm{v}'(m_{t+1})\frac{\mathrm{P}_{t-1} + \mathrm{D}_{t+1}}{\mathrm{P}_t}\right]. \tag{31}$$

By the first order condition in Equation (15), this expression is equal to zero. Thus, since $\frac{df}{dm_t} = \mathrm{v}'(m_t)$, by Equations (28) and (30),

$$\mathrm{v}'(m_t) = \pi\beta\mathbb{E}_t\left[\mathrm{v}'(m_{t+1})\frac{\mathrm{P}_{t+1} + \mathrm{D}_{t+1}}{\mathrm{P}_t}\right]. \tag{32}$$

Now, by the FOC in Equation (15),

$$\pi\beta\mathbb{E}_t\left[\mathrm{v}'(m_{t+1})\frac{\mathrm{P}_{t+1} + \mathrm{D}_{t+1}}{\mathrm{P}_t}\right] = (1-\pi)\,\mathrm{U}'(\zeta_t)\,\mathrm{u}'(s_t). \tag{33}$$

Therefore,

$$\mathrm{v}'(m_t) = (1-\pi)\,\mathrm{U}'(\zeta_t)\,\mathrm{u}'(s_t).$$

□

Proof of Proposition 1. Since intrinsic utility U^i is linear, by Equation (17), in equilibrium

$$\frac{\mathrm{u}^{i\prime}\ s_{t+1}^i}{\mathrm{u}^{i\prime}\ s_t^i} = \frac{\mathrm{u}^{j\prime}\left(s_{t+1}^j\right)}{\mathrm{u}^{j\prime}\left(s_t^j\right)}, \tag{34}$$

for every time t and every pair of consumers i and j. When the induced utility, u^i, is linear, $\frac{\mathrm{u}^{i\prime}\left(s_{t+1}^i\right)}{\mathrm{u}^{i\prime}\left(s_t^i\right)} = 1$

for each consumer i in every time t, regardless of the savings. When the induced utility u^i is strictly concave, suppose that there exists an equilibrium allocation such that $s_t^i < s_{t+1}^i$ for some i. Since aggregate resources are fixed, there must be some consumer j for whom $s_t^j > s_{t+1}^i$. But, since u^i is strictly concave, then

$$\frac{\mathrm{u}^{i\prime} \quad s_{t+1}^i}{\mathrm{u}^{i\prime} \quad s_t^i} \quad < \quad \frac{\mathrm{u}^{j\prime}\left(s_{t+1}^j\right)}{\mathrm{u}^{j\prime}\left(s_t^j\right)}, \tag{35}$$

which violates Equation (17). Thus, $s_t^i = s_{t+1}^i$ and $\frac{\mathrm{u}^{i\prime}\left(s_{t+1}^i\right)}{\mathrm{u}^{i\prime}\left(s_t^i\right)} = 1$ for every consumer i. That is, in both cases, when u^i is either linear or concave, $\frac{\mathrm{u}^{i\prime}\left(s_{t+1}^i\right)}{\mathrm{u}^{i\prime}\left(s_t^i\right)} = 1$. Therefore, Equation (18) can be simplified to $\mathrm{P}_t^* = \overline{\mathrm{D}} \quad {}_{t=1}^{\infty} \pi^t$. Since $\pi < 1$, this geometric sum simplifies to $\mathrm{P}_t^* = \frac{\pi \overline{\mathrm{D}}}{1-\pi}$ for all t.

Concerning the second part of the proposition, since u^i is strictly concave, equilibrium savings are constant over time for every consumer i, which defines a unique savings level $s_t^i = s_{t+1}^i = s^{i*}$ for each consumer i. □

Proof of Proposition 2. By Equation (17), in equilibrium,

$$\frac{\mathrm{U}^{i\prime} \quad \zeta_{t+1}^i}{\mathrm{U}^{i\prime} \quad \zeta_t^i} \frac{\mathrm{u}^{i\prime} \quad s_{t+1}^i}{\mathrm{u}^{i\prime} \quad s_t^i} \quad = \quad \frac{\mathrm{U}^{j\prime}\left(\zeta_{t+1}^j\right)}{\mathrm{U}^{j\prime}\left(\zeta_t^j\right)} \frac{\mathrm{u}^{j\prime}\left(s_{t+1}^j\right)}{\mathrm{u}^{j\prime}\left(s_t^j\right)} \tag{36}$$

for all consumers i, j and $t > 0$. Since $\zeta_{t+1}^i = \zeta_t^i + c_{t+1}^i > \zeta_t^i$ (i.e., interiority is assumed and no borrowing is allowed) and U^i is strictly concave by assumption, then $\frac{\mathrm{U}^{i\prime}\left(\zeta_{t+1}^i\right)}{\mathrm{U}^{i\prime}\left(\zeta_t^i\right)} < 1$ for every consumer i. Suppose that $\frac{\mathrm{U}^{i\prime}\left(\zeta_{t+1}^i\right)}{\mathrm{U}^{i\prime}\left(\zeta_t^i\right)} \frac{\mathrm{u}^{i\prime}\left(s_{t+1}^i\right)}{\mathrm{u}^{i\prime}\left(s_t^i\right)} \geq 1$. Then $\frac{\mathrm{u}^{i\prime}\left(s_{t+1}^i\right)}{\mathrm{u}^{i\prime}\left(s_t^i\right)} > 1$, and thus $s_{t+1}^i < s_t^i$ for all i. Such an allocation, however, is not feasible since total resources are fixed. Thus, $\frac{\mathrm{U}^{i\prime}\left(\zeta_{t+1}^i\right)}{\mathrm{U}^{i\prime}\left(\zeta_t^i\right)} \frac{\mathrm{u}^{i\prime}\left(s_{t+1}^i\right)}{\mathrm{u}^{i\prime}\left(s_t^i\right)} < 1$ for all i and t. The sum in Equation (18) is then less than $\overline{\mathrm{P}}^*$, for which $\frac{\mathrm{U}^{i\prime}\left(\zeta_{t+1}^i\right)}{\mathrm{U}^{i\prime}\left(\zeta_t^i\right)} \frac{\mathrm{u}^{i\prime}\left(s_{t+1}^i\right)}{\mathrm{u}^{i\prime}\left(s_t^i\right)} = 1$ for every t. □

Proof of Proposition 3. In equilibrium, Equation (17) must be satisfied for all consumers at every period t. Thus,

$$-\gamma^i c_{t+1}^i + \ln \frac{\mathrm{u}^{i\prime} \quad s_{t+1}^i}{\mathrm{u}^{i\prime} \quad s_t^i} \quad = \quad -\gamma^j c_{t+1}^j + \ln \frac{\mathrm{u}^{j\prime}\left(s_{t+1}^j\right)}{\mathrm{u}^{j\prime}\left(s_t^j\right)} \tag{37}$$

for all i, j. Let s^{i*} be consumer i's saving in steady state. First, to show that there exists a *unique* feasible allocation such that $s_t^i = s_{t+1}^i = s^{i*}$ for each i and Equation (37) is satisfied for every pair of consumers i and j, suppose to the contrary that there exists an allocation such that $s_t^i = s_{t+1}^i > s^{i*}$ for some i. Since resources are fixed, then there exists $s_t^j = s_{t+1}^j < s^{j*}$ for some consumer j. Since c_{t+1}^i is increasing in s_{t+1}^i and by construction $\ln\left[\frac{\mathrm{u}^{i\prime}\left(s_{t+1}^i\right)}{\mathrm{u}^{i\prime}\left(s_t^i\right)}\right] = 0$, then $\gamma^i c_{t+1}^i > \gamma^i \mathrm{u}^i \quad s_{t+1}^{i*} \quad = \gamma^j \mathrm{u}^j\left(s_{t+1}^{j*}\right) > \gamma^j c_{t+1}^j$, a violation of Equation (37). Therefore, s^{i*} is unique for each consumer i.

When u^i is linear, $\ln\left[\frac{\mathrm{u}^{i\prime}\left(s_{t+1}^i\right)}{\mathrm{u}^{i\prime}\left(s_t^i\right)}\right] = 0$ for any s_t^i and s_{t+1}^i, which completes the proof for this case. Assume now that u^i is strictly concave. Let Z_{t+1} be the equilibrium value of Equation (37) at time t.

That is,

$$Z_{t+1} \equiv -\gamma^i \mathrm{u}^i\left(s_{t+1}^i\right) + \ln \frac{\mathrm{u}^{i\prime} \; s_{t+1}^i}{\mathrm{u}^{i\prime} \; s_t^i} \quad , \tag{38}$$

for every consumer i and j. In a steady state equilibrium, $Z_{t+1} = -\gamma^i \mathrm{u}^i \;\; s_{t+1}^{i*}$, denoted Z^*. Suppose at time t a nonempty set of consumers $I_t = \;\; i : s_t^i > s^{i*} \;\;$. Then, by Equation (37), there exists a nonempty set of consumers $J_t = \left\{j : s_t^j < s^{j*}\right\}$. Let $H_t = \left\{h : s_t^h = s^{h*}\right\}$, which may be empty. To prove convergence, it is sufficient to show that $\underset{\ell \in L}{\;} s_{t+1}^\ell - s^{\ell*} \;\; < \underset{\ell \in L}{\;} s_t^\ell - s^{\ell*}$, where $L = H \cup I \cup J$ is the set of all consumers.

First, suppose that $Z_{t+1} = Z^*$. Since u^i is strictly increasing and strictly concave, $s_t^i > s_{t+1}^i > s^{i*}$ for any $i \in I_t$, and $s_t^j < s_{t+1}^j < s^{j*}$ for any $j \in J_t$; otherwise Equation (37) does not hold. Further, $s_{t+1}^h = s_t^h = s^{h*}$ for $h \in H_t$. Thus, $\underset{\ell \in L}{\;} s_{t+1}^\ell - s^{\ell*} \;\; < \underset{\ell \in L}{\;} s_t^\ell - s^{\ell*}$.

Next, suppose $Z_{t+1} > Z^*$. Equation (37) then implies that $s_{t+1}^j < s^{j*}$ for all $j \in J_t$, $s_{t+1}^h < s^{h*}$ for all $h \in H_t$, and $s_{t+1}^i < s_t^i$ for all $i \in I_t$. Split I_t into $A_t = \;\; i : i \in I_t, \; s_{t+1}^i \leq s^{i*} \;\;$, which may be empty, and $B_t = \;\; i : i \in I_t, \; s^{i*} < s_{t+1}^i < s_t^i \;\;$.[56] Since total resources are fixed, $\underset{i \in I_t}{\;} s_t^i - s^{i*} \;\; = \underset{j \in J_t}{\;} s_t^j - s^{j*}$, and since in addition $s_{t+1}^j < s^{j*}$ for all $j \in A_t \cup H_t \cup J_t$, then $\underset{i \in B_t}{\;} s_{t+1}^i - s^{i*} \;\; = \underset{j \in A_t \cup H_t \cup J_t}{\;} s_{t+1}^j - s^{j*}$. But, by the definition of B_t, $\underset{i \in B_t}{\;} s_{t+1}^i - s^{i*} \;\; < \underset{i \in I_t}{\;} s_t^i - s^{i*}$. Thus, $\underset{\ell \in L}{\;} s_{t+1}^\ell - s^{\ell*} \;\; < \underset{\ell \in L}{\;} s_t^\ell - s^{\ell*}$. Since this holds for any t, $\lim_{t \to \infty} \underset{\ell \in L}{\;} s_t^\ell - s^{\ell*} \;\; = 0$. Therefore, $\lim_{t \to \infty} s_t^\ell = s^{\ell*}$, for every consumer ℓ. The proof for $Z_{t+1} < Z^*$ is similar. □

Proof of Proposition 4. When U^i is DARA, as $t \to \infty$, U^i tends to a linear form. Then, by Proposition 1, price converges to $\overline{\mathrm{P}}^*$, and if u^i is strictly concave, savings satisfy $s_t^i = s_{t+1}^i = s^{i*}$. □

Proof of Proposition 5. Let $i = \{1, 2\}$ denote the two types of consumers. By Equation (17),

$$\left(\frac{c_1^1}{c_1^1 + c_2^1}\right)^\gamma \left(\frac{s_1^1}{s_2^1}\right)^\delta = \left(\frac{c_1^2}{c_1^2 + c_2^2}\right)^\gamma \left(\frac{s_1^2}{s_2^2}\right)^\delta . \tag{39}$$

By Walras' Law, let $s_t^1 = \bar{S} x_t$ and $s_t^2 = \bar{S}\left(1 - x_t\right)$, where $x_t \in (0, 1)$, and $\bar{S}$ is the total possible savings. Then, substitution this using $c_t^i = \frac{\left(s_t^i\right)^{1-\delta}}{1-\delta}$ into Equation (39), provides

$$\left(\frac{x_1^{1-\delta}}{x_1^{1-\delta} + x_2^{1-\delta}}\right)^\gamma \left(\frac{x_1}{x_2}\right)^\delta = \frac{\left(1 - x_1\right)^{1-\delta}}{\left(1 - x_1\right)^{1-\delta} + \left(1 - x_2\right)^{1-\delta}}^{\;\gamma} \left(\frac{1 - x_1}{1 - x_2}\right)^\delta . \tag{40}$$

Since the left hand side of Equation (39) decreases in x_2 and the right hand side increases in x_2, the solution $x_1 = x_2$ is unique. Thus,

$$\left(\frac{c_1^1}{c_1^1 + c_2^1}\right)^\gamma \left(\frac{s_1^1}{s_2^1}\right)^\delta = \left(\frac{1}{2}\right)^\gamma . \tag{41}$$

Similarly, in the following period,

$$\left(\frac{c_1^1 + c_2^1}{c_1^1 + c_2^1 + c_3^1}\right)^\gamma \left(\frac{s_2^1}{s_3^1}\right)^\delta = \left(\frac{2}{3}\right)^\gamma , \tag{42}$$

[56] Note that $j \in H_t \cup J_t$ implies $j \in J_{t+1}$, while $i \in I_t$ can be a member of I_{t+1}, J_{t+1}, or H_{t+1}.

and so on, such that in period t

$$\left(\frac{\zeta_t^1}{\zeta_t^1 + c_{t+1}^1}\right)^{\gamma} \left(\frac{s_t^1}{s_{t+1}^1}\right)^{\delta} = \left(\frac{t}{t+1}\right)^{\gamma}. \tag{43}$$

The result then follows by substituting this sequence into Equation (18). □

Proof of Corollary 1. Immediately obtained by Equation (23). □

B Regression Results

Table B.1: **OLS Regression of Final Shares on HL Scores with Session Fixed Effects, Linear Treatments (Clustered Standard Errors)**

$s_i = \beta_0 + \beta_1 h_i +$ (session dummies) $+\varepsilon_i$

s_i = average shares of subject i during the final 2 periods of the (linear) session

h_i = HL score of subject i in the (linear) session

	Coefficient	Standard Error	z	$P > \|z\|$	[95% Confidence Interval]
β_1	0.6496689	0.1894655	3.43	0.014	[.1860635, 1.113274]
β_2 (S7)	-1.245199	.3631422	-3.43	0.014	[-2.133776, -.3566218]
β_3 (S10)	-1.245199	.3631422	-3.43	0.014	[-2.133776, -.3566218]
β_4 (S12)	-.9203642	.2684094	-3.43	0.014	[-1.577138, -.26359]
β_5 (S16)	-.6496689	.1894655	-3.43	0.014	[-1.113274, -.1860635]
β_6 (S18)	-.1082781	.0315776	-3.43	0.014	[-.1855457, -.0310106]
β_7 (S20)	-.1624172	.0473664	-3.43	0.014	[-.2783186, -.0465159]
β_0 (S13)	.4427152	.599974	0.74	0.488	[-1.025368, 1.910799]

R-squared: 0.1072, Root MSE: 3.412

Table B.2: **OLS Regression of Final Shares on HL Score Shares, Linear**

$s_i = \beta_0 + \beta_1 h_i + \varepsilon_i$

s_i = average shares of subject i during the final 2 periods of the (linear) session

h_i = HL score of subject i divided by the sum of HL scores within the session

	Coefficient	Standard Error	z	$P > \|z\|$	[95% Confidence Interval]
β_1	39.8056	9.7839	4.068	0.000108	
β_0	-0.8611	0.8957	-0.961	0.339147	

Residual standard error: 3.171 on 82 degrees of freedom

Multiple R-squared: 0.168, Adjusted R-squared: 0.1578

F-statistic: 16.55 on 1 and 82 DF, p-value: 0.0001082

Table B.3: **OLS Regression of Final Shares on HL Scores, Concave (Clustered Standard Errors)**

$s_i = \beta_0 + \beta_1 h_i + \varepsilon_i$

s_i = average shares of subject i during the final 2 periods of the (concave) session

h_i = HL score of subject i in the (concave) session

	Coefficient	Standard Error	z	$P > \|z\|$	[95% Confidence Interval]
β_1	-.1603221	.0925407	-1.73	0.134	[-.3867609, .0661167]
β_2 (S8)	-.1736823	.1002524	-1.73	0.134	[-.418991, .0716264]
β_3 (S9)	-.0801611	.0462703	-1.73	0.134	[-.1933805, .0330584]
β_4 (S14)	-.0935212	.053982	-1.73	0.134	[-.2256105, .0385681]
β_5 (S15)	-.1202416	.0694055	-1.73	0.134	[-.2900707, .0495875]
β_6 (S17)	-.0534407	.0308469	-1.73	0.134	[-.1289203, .0220389]
β_7 (S19)	-.0935212	.053982	-1.73	0.134	[-.2256105, .0385681]
β_0 (S11)	3.168009	.3855861	8.22	0.000	[2.224514, 4.111504]
R-squared: 0.0198, Root MSE: 1.9522					

Table B.4: **Linear Regression of HL Score on Treatment Dummies and Earnings**

$h_i = \beta_0 + \beta_1 Linear + \beta_2 D3 + \beta_3 Pay_i + \epsilon_i$

h_i = subject i's Holt Laury score

Linear: linear treatment dummy

D3: $d = 3$ treatment dummy

Pay_i = subject i's earnings

OLS Regression	Number of obs = 168
R^2 (overall): 0.0187	Wald $\chi^2(3) = 2.91$
corr$(u_i, X) = 0$ (assumed)	Prob > χ^2=0.4929

h_i	Coef.	Std. Error	t	$P > \|t\|$	[95% Confidence Interval]
β_1	0.4600691	0.3574489	1.29	0.198	[-0.2405178, 1.160656]
β_2	-0.0141679	0.3217259	-0.04	0.965	[-0.6447392, 0.6164033]
β_3	0.0139502	0.0277779	0.50	0.616	[-0.0404934, 0.0683939]
β_0	3.430148	0.4083777	8.40	0.000	[2.629742, 4.230554]

Table B.5: **OLS Regression of Final Shares on HL Scores, L2-10 Choice**

$s_i = \beta_0 + \beta_1 h_i + \varepsilon_i$

s_i = average shares of subject i during the final 2 periods of the session

h_i = HL score of subject i in the session

	Coefficient	Standard Error	z	$P > \|z\|$	
β_1	0.9306	0.4006	2.323	0.0337	
β_0	0.1713	1.5745	0.109	0.9147	

Residual standard error: 2.404 on 16 degrees of freedom

Multiple R-squared: 0.2522, Adjusted R-squared: 0.2054

F-statistic: 5.395 on 1 and 16 DF, p-value: 0.0337

Table B.6: **OLS Regression of Final Shares on HL Scores, L2-13 Choice**

$s_i = \beta_0 + \beta_1 h_i + \varepsilon_i$

s_i = average shares of subject i during the final 2 periods of the session

h_i = HL score of subject i in the session

	Coefficient	Standard Error	z	$P > \|z\|$	
β_1	-0.1923	0.6911	-0.278	0.784	
β_0	2.8526	2.8863	0.988	0.338	

Residual standard error: 3.524 on 16 degrees of freedom

Multiple R-squared: 0.004817, Adjusted R-squared: -0.05738

F-statistic: 0.07744 on 1 and 16 DF, p-value: 0.7844

Table B.7: **OLS Regression of Final Shares on HL Scores, Linear Market Low Price**

$s_i = \beta_0 + \beta_1 h_i + \varepsilon_i$

s_i = average shares of subject i during the final 2 periods of the session

h_i = HL score of subject i in the session

	Coefficient	Standard Error	z	$P > \|z\|$	
β_1	0.3942	0.2440	1.615	0.113	
β_0	0.8987	1.1053	0.813	0.420	

Residual standard error: 3.388 on 46 degrees of freedom

Multiple R-squared: 0.05369, Adjusted R-squared: 0.03311

F-statistic: 2.61 on 1 and 46 DF, p-value: 0.1131

Table B.8: **OLS Regression of Final Shares on HL Scores, Linear Market High Price**

$s_i = \beta_0 + \beta_1 h_i + \varepsilon_i$

s_i = average shares of subject i during the final 2 periods of the session

h_i = HL score of subject i in the session

	Coefficient	Standard Error	z	$P > \|z\|$	
β_1	0.8129	0.3145	2.585	0.0142	
β_0	-0.9097	1.4266	-0.638	0.5280	

Residual standard error: 3.262 on 34 degrees of freedom

Multiple R-squared: 0.1643, Adjusted R-squared: 0.1397

F-statistic: 6.683 on 1 and 34 DF, p-value: 0.0142