An Experimental Test of the Lucas Asset Pricing Model

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December 24, 2017

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 values in environments without 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.

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§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. Funding for this project was provided by the Dietrich School of Arts and Sciences of the University of Pittsburgh.
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. 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).

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 data examined by the 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.

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. 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

\footnote{For surveys, see e.g., Campbell (2018), Cochrane (2005) and Lengwiler (2009).}

\footnote{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.”}

\footnote{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.}

\footnote{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.\(^6,7\) In most of these experiments, asset price bubbles turn out to be difficult to eliminate.

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

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\(^5\)Key papers include Porter and Smith (1995), Lei et al. (2001), Dufwenberg, et al. (2005), Haruuy and Noussair (2006), Haruuy 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.
the language of Lucas (1978) francs are perishable “fruit” that get consumed each period, while assets are potentially long-lived “trees.”

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 demonstrate that, when subjects are weakly risk averse, both our linear and concave indefinite horizon treatments feature the same steady state equilibrium price, which is weakly less than the steady state price in the analogous infinite horizon economy. To explain the variation in individual behavior, we measure subjects’ risk tolerance 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. Experimental explorations of intertemporal consumption-smoothing (excluding tradeable assets) is the focus of several papers. 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.

The main findings of our experiment can be summarized as follows. First, in our linear exchange rate treatment (no induced motive to trade), we observe sustained prices above fundamentals; on average, prices are 32% above the asset’s fundamental value in these sessions. However, the frequency, magnitude, and duration of such bubbles is significantly reduced in our concave exchange rate treatment, where assets trade at an average discount of 24% relative to fundamentals. 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,

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8Notice 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.

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 additional individual choice experiments in which subjects can trade with the experimenter at a known, constant price. In these experiments, the only uncertainty subjects face 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 in the linear exchange rate condition are less likely to hold large share quantities at high prices relative to the market experiment, suggesting a speculative motive for bubbles in the linear market experiment.

In related research, Asparouhova et al. (2016) implement a Lucas asset experiment in which there are short-lived francs and two long-lived assets: trees yielding stochastic dividends and risk-free (consol) bonds. Rather than induce consumption-smoothing through a concave exchange rate, subjects are paid only for francs held in the terminal period of the indefinite horizon. Thus, the authors rely on innate 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 terminal. 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 not far from competitive equilibrium levels when there is an induced motive to intertemporally smooth consumption.

2 The Lucas asset pricing framework
In this section, we first describe a Lucas (1978) infinite horizon economy. We next 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. In that case, we prove convergence to a steady state equilibrium.
that is weakly less than the fundamental price of the asset under weakly risk-averse 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 \( k^i_t \) the number of shares of the asset that consumer \( i \) owns at the beginning of period \( t \), with initial endowment \( k^i_0 \).

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 \( U^i : \mathbb{R}_+ \to \mathbb{R} \) that vanishes at zero.\(^{10}\) That is, \( U^{ii'}(c^i_t) > 0, U^{ii''}(c^i_t) < 0 \), and \( U^i(0) = 0 \), where \( c^i_t \) 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 \( y^i_t \), 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,

\[
y^i_t + D_t k^i_t + P_t k^i_{t+1} = c^i_t + P_t k^i_{t+1},
\]

which implies that

\[
k^i_{t+1} = \left(1 + \frac{D_t}{P_t}\right) k^i_t + \frac{1}{P_t} \left(y^i_t - c^i_t\right).
\]

Equation (1) also implies the market clearing conditions

\[
K = \sum_i k^i_t \quad \text{and} \quad C_t = \sum_i c^i_t,
\]

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,

\[
C_t = Y_t + D_t K,
\]

where \( Y_t = \sum_i y^i_t \) is the aggregate endowment in the economy at time \( t \).

\(^{10}\mathbb{R}_+ \) stands for the set of nonnegative real numbers, i.e., \( \mathbb{R}_+ = \{x \mid x \geq 0, x \in \mathbb{R}\} \).
Each consumer, \(i\), faces the following objective function,

\[
v^i(m^i_0) = \max_{\{c^i_t\}_{t=0}^\infty} \mathbb{E}^i_0 \left[ \sum_{t=0}^\infty \beta^t U^i(c^i_t) \right]
\]

subject to

\[
k^i_{t+1} = (1 + \frac{D_t}{P_t}) k^i_t + \frac{1}{P_t} (y^i_t - c^i_t)
\]

\[
m^i_{t+1} = (P_{t+1} + D_{t+1}) k^i_{t+1}
\]

where, to rule out non-fundamental solutions, the transversality condition

\[
\lim_{t \to \infty} \mathbb{E}_t^i \left[ \beta^T U^i_t(c^i_{t+\tau})(P_{t+\tau} + D_{t+\tau}) k^i_{t+\tau} \right] = 0
\]

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 \(m^i_{t+1}\) 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,

\[
c^i_t = y^i_t + (P_t + D_t) k^i_t - P_t k^i_{t+1}.
\]

Since neither borrowing nor short selling are permitted, we must have that \(c^i_t \geq 0\) and \(k^i_t \geq 0\). Hence, when the solution to the maximization problem in Equation (5) implies \(c^i_t < 0\) or \(k^i_t < 0\), a boundary solution is obtained since utility functions are strictly monotonic. The same holds when the solution implies that \(k^i_t > K\). 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

\[
v^i(m^i_t) = \max_{\{c^i_t\}} U^i(c^i_t) + \beta \mathbb{E}_t^i \left[ v^i(m^i_{t+1}) \right],
\]

with the transversality condition

\[
\lim_{\tau \to \infty} \beta^{\tau} \mathbb{E}^i_t \left[ v''(m^i_{t+\tau}) m^i_{t+\tau} \right] = 0.
\]

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

\[
0 = U'(c^i_t) - \beta \mathbb{E}_t^i \left[ \frac{U''(m^i_{t+1})}{U'(c^i_t)} (P_{t+1} + D_{t+1}) \right],
\]

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

\[
v''(m^i_{t+1}) = U''(c^i_{t+1}).
\]

Thus, the FOC in Equation (8) becomes

\[
P^*_t = \beta \mathbb{E}_t^i \left[ \frac{U'(c^i_{t+1})}{U'(c^i_t)} (P_{t+1} + D_{t+1}) \right],
\]

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

\[
P^*_t = \mathbb{E}_t^i \left[ \sum_{\tau=1}^{\infty} \beta^{\tau} \frac{U'(c^i_{t+\tau})}{U'(c^i_t)} D_{t+\tau} \right].
\]

\(^{11}\)When \(U^i\) is linear, the transversality condition need not hold; in that case, non-fundamental bubble solutions are possible.
The term $\beta \frac{U_i'(c_{i+\tau})}{U_i'(c_i)}$ is referred to as the stochastic discount factor, and the term $\frac{U_i''(c_{i+\tau})}{U_i''(c_i)}$ 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. When all consumers have the same utility function and beliefs, Equation (11) holds for such a “representative” consumer. Because the utility function is strictly monotonic, markets clear. Finally, by Lucas (Proposition 1, 1978), the pairs $v(m_t)$ 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, $\pi$. 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 $u^i : \mathbb{R}_+ \rightarrow \mathbb{R}_+$ at the end of each period. This exchange function is strictly monotonic, strictly concave, bounded, twice continuously differentiable, and vanishes at zero.

The exchange function is applied to control a subject 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 henceforth refer to $U^i$ as the unobserved “intrinsic” 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 agents are intrinsically risk neutral, but we will also consider cases where agents are intrinsically risk averse as well.

In each period $t$, consumer $i$ chooses a quantity, $s^i_t$, of francs to convert (save) into dollars, $c^i_t = u^i(s^i_t)$, which is added to her accumulated consumption quantity (experimental earnings) $\zeta^i_t = \sum_{\tau=0}^t c^i_\tau$. These consumption earnings are not available to subjects 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 $\pi$ or ends with probability $1 - \pi$. If the economy ends, then all asset shares vanish and consumption of the accumulated dollars takes place. If the economy continues, then shareholdings

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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 That is, $u''(\cdot) > 0$, $u'''(\cdot) < 0$ and $u'(0) = 0$.

14 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.
carry over to the next period.

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

\[
 v^i(m^i_0) = \max_{\{s^i_t\}_{t=0}^\infty} \mathbb{E}_t^i \left[ \sum_{t=0}^\infty (1 - \pi) \pi^t \beta^t U^i(\zeta^i_t) \right] \tag{12} \\
\text{s.t.} \quad k^i_{t+1} = \left(1 + \frac{D^i_t}{P^i_t}\right) k^i_t + \frac{1}{P^i_t} (y^i_t - s^i_t) \\
 m^i_{t+1} = (P^i_{t+1} + D^i_{t+1}) k^i_{t+1} \\
 \zeta^i_t = \sum_{\tau=0}^t c^i_\tau \\
 c^i_t = u^i_t (y^i_t + D^i_t k^i_t + P^i_t (k^i_t - k^i_{t+1})) , 
\]

where the transversality condition \( \lim_{\tau \to \infty} \mathbb{E}_t^i [(1 - \pi) \pi^\tau \beta^\tau U^i(\zeta^i_{t+\tau}) u^i(\zeta^i_{t+\tau}) (P^i_{t+\tau} + D^i_{t+\tau}) k^i_{t+\tau}] = 0 \) is assumed to hold.\(^{15}\) The first constraint can be rewritten to define the quantity of francs that consumer \( i \) converts into dollars (saves) at time \( t \),

\[
s^i_t = y^i_t + D^i_t k^i_t + P^i_t (k^i_t - k^i_{t+1}) . \tag{13}
\]

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

\[
v^i(m^i_0) = \max_{\{s^i_t\}} (1 - \pi) U^i(\zeta^i_0) + \pi \beta \mathbb{E}_t^i \left[ v^i(m^i_{t+1}) \right] \tag{14}
\]

with the transversality condition \( \lim_{\tau \to \infty} (1 - \pi) \pi^\tau \beta^\tau \mathbb{E}_t^i \left[ v^{i*}(m^i_{t+\tau}) m^i_{t+\tau} \right] = 0 \). The FOC of an interior solution of this problem is then

\[
0 = (1 - \pi) U^{i*}(\zeta^i_t) u^{i*}(s^i_t) - \pi \beta \mathbb{E}_t^i \left[ v^{i*}(m^i_{t+1}) \frac{P_{t+1} + D_{t+1}}{P^i_t} \right] . \tag{15}
\]

By Lemma 1 (see Appendix),

\[
v^{i*}(m^i_{t+1}) = (1 - \pi) U^{i*}(\zeta^i_{t+1}) u^{i*}(s^i_{t+1}) . \tag{16}
\]

Thus, the equilibrium price satisfies

\[
P^*_t = \pi \beta \mathbb{E}_t^i \left[ \frac{U^{i*}(\zeta^i_{t+1}) u^{i*}(s^i_{t+1})}{U^{i*}(\zeta^i_t) u^{i*}(s^i_t)} (P^i_{t+1} + D^i_{t+1}) \right] , \tag{17}
\]

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

\[
P^*_t = \mathbb{E}_t^i \left[ \sum_{r=1}^\infty \pi^r \beta^r \frac{U^{i*}(\zeta^i_{t+r}) u^{i*}(s^i_{t+r})}{U^{i*}(\zeta^i_t) u^{i*}(s^i_t)} D^i_{t+r} \right] . \tag{18}
\]

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)

\(^{15}\) 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.
simplifies to Equation (11) provided that: (i) The continuation probability, $\pi$, 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 risk neutral with respect to the uncertain amounts of money they earn in our experiment.

2.3 The model implemented in the laboratory

In implementing 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, $D_t = D$. Second, aggregate resources $S_t = \sum_i s^i_t$ are held constant over time, so that $S_t = \bar{S}$ for all $t$. Third, the endowment, $y^i_t$, that each consumer $i$ receives is deterministic and 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.

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, $E^i_t [\cdot]$, in Equations (17) and (18); the only uncertainty is horizon uncertainty, i.e., whether period $t + \tau$ will be reached. When both the intrinsic and induced utilities are linear, Equation (18) becomes

$$P^* = \frac{D}{\sum_{t=1}^{\infty} \pi^t}.$$  \hspace{1cm} (19)

We next show that, regardless of the induced utility function ($u^i$), when all consumers have weakly risk averse (and possibly heterogeneous) intrinsic utilities ($U^i$), the equilibrium price in every period is weakly less than the fundamental price given by Equation (19). Further, the economy converges to a unique steady state equilibrium in which the price and the consumption of each consumer is constant across periods. Specifically, when all consumers have intrinsic, constant absolute risk aversion (CARA) utility, the steady state price is weakly less than the fundamental price (the relationship is strict if all consumers are strictly risk averse). When all consumers have intrinsic, decreasing absolute risk aversion (DARA) utility, the equilibrium price sequence converges to the fundamental price from below. We emphasize that in both cases, the steady state price does not depend on the induced utility.

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16This 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.

17When 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.
function, \( u^i \). Thus, we satisfy a core goal of our experimental design, connecting the SSW experimental asset pricing framework with the Lucas asset pricing model by introducing an induced incentive to smooth consumption, while keeping the underlying steady state fundamentals constant.

When the intrinsic utility function \( U^i \) is **CARA**, accumulated wealth does not affect a consumer’s current portfolio choice. 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 \( U^i \). The CARA utility function can be specified as

\[
U^i \left( \zeta^i_t \right) = \frac{1 - e^{-\gamma^i \zeta^i_t}}{\gamma^i}.
\]  

(20)

Each consumer \( i \)'s intrinsic risk aversion is summarized by parameter \( \gamma^i > 0 \), where risk aversion is increasing in \( \gamma^i \). Since in equilibrium Equation (17) must be satisfied for all consumers at every period \( t \), we must have that

\[
\gamma^i c^i_{t+1} - \ln \left( \frac{u'^i(s^j_{t+1})}{u'^i(s^j_t)} \right) = \gamma^j c^j_{t+1} - \ln \left( \frac{u'^j(s^j_{t+1})}{u'^j(s^j_t)} \right)
\]

(21)

for all \( i, j \).

We first show there exists a unique allocation in which \( s^i_t = s^i_{t+1} = s^{i*} \) for every \( i \) and Equation (21) is satisfied for any pair \( i \) and \( j \). To see why this is true, suppose to the contrary there exists a second such allocation, and thus \( s^i_t = s^i_{t+1} > s^{i*} \) for some \( i \) (since aggregate resources are fixed). Since \( c^i_{t+1} = u^i(s^i_{t+1}) \) is increasing in \( s^i_{t+1} \), and \( \ln \left( \frac{u'^i(s^i_{t+1})}{u'^i(s^i_t)} \right) = 1 \) (because \( s^i_t = s^i_{t+1} \) by assumption), then by Equation (21) we have \( c^i_{t+1} > u^i(s^{i*}_{t+1}) \) for all consumers \( j \), which violates the constant aggregate resource constraint (since then \( \sum_j s^j_{t+1} > \sum_j s^{j*} = S \)).

We next show that any equilibrium sequence of savings for each consumer \( i \) converges to \( s^{i*} \) (which thus represents a steady state equilibrium). Suppose \( s^i_{t+1} \neq s^{i*} \) for each consumer \( i \) and Equation (21) is satisfied. Then subjects can be partitioned into two groups \( I \) and \( J \), where \( s^i_{t+1} > s^{i*} \) for every \( i \in I \) and \( s^j_{t+1} < s^{j*} \) for every \( j \in J \). Since \( u'^i \) and \( u'^j \) are decreasing functions (\( u^i \) and \( u^j \) are concave) and resources in the economy are fixed, to satisfy Equation (21), it must be true that \( s^i_t > s^i_{t+1} \) for all \( i \in I \), and \( s^j_t < s^j_{t+1} \) for all \( j \in J \). This means that the sequence \( \{s^i_j \}_{t=0}^\infty \) is strictly increasing for every \( j \in J \), and the sequence \( \{s^i_t \}_{t=0}^\infty \) is strictly decreasing for every \( i \in I \). Because allocation \( s^{i*} \) is unique, \( \{s^i_t \}_{t=0}^\infty \) converges to \( s^{i*} \) for each consumer \( i \in I \cup J \) in the limit as \( t \) goes to infinity.

Consider Equation (17) in light of this result. Note that \( \frac{u'^i(s^i_{t+1})}{u'^i(s^i_t)} < 1 \) for every \( t \). Suppose \( s^j_t < s^j_{t+1} \) for some consumer \( j \). Since resources in the economy are fixed, there is a consumer \( i \) with shareholdings \( s^i_t > s^i_{t+1} \). This implies that, concerning consumer \( j \), \( \frac{u'^j(s^j_{t+1})}{u'^j(s^j_t)} < 1 \) and therefore the product of her intrinsic and induced marginal rates of substitution in Equation (17) is less than one.

\(^{18}\)Since aggregate resources are fixed, \( I \) is an empty set if and only if \( J \) is an empty set. The case where some subjects initially have \( s^i_{t+1} = s^{i*} \) is easily accommodated.
By Equation (21), in equilibrium, this is also true for consumer $i$. Therefore, under intrinsic CARA utility, $P_t^i < \hat{P}^*$ for every $t$, and the equilibrium price sequence converges to the steady state price
\[ \hat{P}^* = \frac{\pi D}{e^{\gamma c^i} - \pi}. \] (22)

Note that $\hat{P}^*$ does not depend on induced utility $u^i$ and is decreasing in the intrinsic risk aversion of each consumer, $\gamma^i$; that is, for a given distribution of endowments and preferences, $\hat{P}^*$ must decline if $\gamma^i$ increases for some $i$. And as $\gamma^i$ approaches zero for any $i$, the steady state price converges to the fundamental price in Equation (19) (and thus a risk-neutral consumer sets the market price). Finally, since $s_t^i = s_{t+1}^i = s^*$ for all $i$ implies that $\gamma^i c^i = \gamma^j c^j$ by Equation (21), then steady state consumption is greater for less risk-averse consumers.

Now, suppose that the intrinsic utility $U^i$ reflects DARA. In this case, risk aversion decreases in accumulated wealth. Clearly, in Equation (17), $\frac{U'^i(\zeta_{t+1})}{U'^i(\zeta^i_t)} < 1$ for every consumer $i$ and every time period $t$. If $s_{t+1}^i < s_t^i$ for some $i$, then constant aggregate resources requires that $s_{t+1}^j > s_t^j$ for some $j$, in which case $\frac{U'^i(\zeta_{t+1})}{U'^i(\zeta^i_t)} w'(s^i_{t+1}) < 1$. Then, by Equation (17), the product of the intrinsic and induced marginal rates of substitution must be less than one for all consumers in all periods. Thus, $u'^i(s_{t+1}^i) > u'^j(s_{t+1}^j).$ Substituting this expression into the inequality from the previous period, we obtain $\frac{U'^i(\zeta_{t+2})}{U'^i(\zeta^i_t)} w'(s^i_{t+2}) < 1.$ Iterating this process over $\tau$ periods provides $\frac{U'^i(\zeta_{t+\tau})}{U'^i(\zeta^i_t)} w'(s^i_t) < 1$ for all $t$. By Equation (18), if $\frac{U'^i(\zeta_{t+\tau})}{U'^i(\zeta^i_t)} w'(s^i_t) = 1$ for all $t$ and $\tau \geq 1$, then $P_t^i = \hat{P}^*$. Therefore, it must be the case that $P_t^i < \hat{P}^*$ for all $t$. However, as wealth grows sufficiently large, $\frac{U'^i(\zeta_{t+1})}{U'^i(\zeta^i_t)}$ converges to one for all $i$, and thus to satisfy Equation (17) for concave $u^i$, it is required that $s_{t+1}^i = s_t^i$ for all $i$ (shareholdings are unrestricted if $u^i$ is linear). Thus, for DARA intrinsic utility, the equilibrium price converges to the fundamental price from below.

In summary, when consumers are intrinsically risk averse, the equilibrium price in each period will be less than or equal to the fundamental price, Equation (19), and will converge to a unique steady state equilibrium price. For DARA or linear intrinsic utility, the emergent price is equal to the fundamental price. While this price does not depend on the induced utility function $u^i$, this induced function nevertheless plays a key role in equilibrium shareholdings, since under the induced concave (but not linear) utility function subjects would find it optimal to use the asset to smooth consumption. For the case of CARA intrinsic utility, the steady state equilibrium price is strictly less than the fundamental price. This price does not depend on the induced utility function, nor does the extent of consumption smoothing in the steady state. Finally, the model also predicts that a higher dividend, $D$, results in an higher steady state price, a prediction we test in our experiment.
2.4 Hypotheses

Based on the theory presented in the previous section, we have the following hypotheses, which we test in our experiment:

**Hypothesis 1.** For a given dividend $\bar{D}$, the induced utility function $u^i$ has no effect on emergent prices. Further, these prices are weakly less than $P^*$. 

An alternative hypothesis, which in consistent with the finding of asset price “bubbles” in SSW, is the following:

**Hypothesis 2.** For a given dividend $\bar{D}$, prices are greater when the induced utility function, $u^i$, is linear as compared with when it is concave.

This alternative hypothesis is motivated by the following reasoning. Consumer $i$’s subjective beliefs, as reflected in the probabilities used to assess $\mathbb{E}_t^i [\cdot]$, impact on the equilibrium price and allocation determined by Equation (17). Scheinkman and Xiong (2003) and Hong et al. (2006) explore how heterogeneous beliefs about the dividend realization can generate equilibrium prices exceeding the asset’s fundamental value. An overconfident or optimistic buyer may consume less to buy more assets, and may end up 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, $\pi$, (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 discussed 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 $P_{t+1} > P_t > P^*$. If this subject buys at date $t$ and sells at date $t+1$, his expected gain is $\pi(P_{t+1} + \bar{D}) - P_t$ 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.\(^{19}\) Alternatively, a subject with

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\(^{19}\)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.
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 would result from such speculation. For this reason, we hypothesize that the inducement of a concave utility function is less likely to result in bubbly prices than an induced linear utility function. Thus, the reason we anticipate a price difference between induced concave and induced linear utility is that subjects facing strictly concave $u^i$ have a stronger incentive to smooth consumption across periods.

**Hypothesis 3.** *When the induced utility, $u^i$, is concave, subjects use the asset to smooth their consumption over time.*

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 $D$.***

**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 model are supported within 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 fundamentals like the dividend, the continuation probability, the induced utility function, and the income process. We are further interested in subjects’ use of the asset to intertemporally smooth their consumption relative to benchmark predictions.

#### 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, $\bar{D}$, 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 the comparative statics predictions of the theory. Second, we examine whether the strength of the consumption-smoothing objective matters, by varying the curvature of the agents’ induced utility function $u^i$ 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.

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20Alternatively, we could have changed other fundamental factors, such as the continuation probability, $\pi$. We chose to vary the dividend, as changes in the dividend process is a common treatment variation in the experimental asset pricing literature.
We adopt a $2 \times 2$ 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, which is either high or low. We conduct twenty laboratory sessions (five per treatment) of the indefinite horizon economy introduced in Section 2.2. 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.

<table>
<thead>
<tr>
<th>$i$</th>
<th># Subjects</th>
<th>$k_i$</th>
<th>${y_i^t}$</th>
<th>$u^i(s_i^t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>1</td>
<td>110 if $t$ is odd 44 if $t$ is even</td>
<td>$\delta^1 + \alpha^1 s_i^1$</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>4</td>
<td>24 if $t$ is odd 90 if $t$ is even</td>
<td>$\delta^2 + \alpha^2 s_i^2$</td>
</tr>
</tbody>
</table>

Table 1: Induced Utility and Endowment Parameters

In each session, the franc endowment, $y_i^t$, 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 $D = 2$ or $D = 3$, 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, $D = 2$), C3 (concave induced utility, $D = 3$), L2 (linear induced utility, $D = 2$), and L3 (linear induced utility, $D = 3$). 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.

The induced utility parameters are chosen so that subjects earn $1$ at the (intrinsic) risk neutral competitive equilibrium in C2 and L2. By contrast, C2 subjects earn on average $0.45$ per period in autarky (no trade). In L2, expected earnings in autarky equals 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 Appendix).

In our baseline treatments C2 and C3, we set $\eta^i < 1$ and $\alpha^i \eta^i > 0$.\textsuperscript{21} Given our cyclic income process, Equation (17) and the budget constraint can be used to show that risk neutral or DARA

\textsuperscript{21}Specifically, $\eta^1 = -1.195$, $\alpha^1 = -311.34$, $\delta^1 = 2.6074$, and $\eta^2 = -1.3888$, $\alpha^2 = -327.81$, $\delta^2 = 2.0627$. 

14
steady-state shareholdings follow a two-cycle between the initial share endowment, \( k_{\text{Even}[t]} = k^i_0 \), and

\[
k^{i}_{\text{Odd}[t]} = k^{i}_{\text{Even}[t]} + \frac{y^{i}_{\text{Odd}[t]} - y^{i}_{\text{Even}[t]}}{2\bar{P} + D}.
\]  

(23)

Notably, in the steady state subjects smooth consumption by buying asset shares during high income periods and selling during low income periods. In C2, by Equation (19), the fundamental price is \( \bar{P}^* = 10 \). In turn, Equation (23) implies that, at the fundamental price equilibrium, a type 1 subject 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. In C3, the fundamental price is \( \bar{P}^* = 15 \), and in equilibrium, a type 1 subject 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.\(^{22}\) 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. By Hypothesis 2, in L2 and L3 assets may trade at prices greater than the fundamental price, \( \bar{P}^* \), in line with SSW’s bubble findings. This, however, contradicts our theoretical predication (Hypothesis 1) that the curvature of induced utility has no impact on the steady state equilibrium price for subjects with weakly concave intrinsic utility functions.

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:

\[
y^i_t + D_t k^i_t + \bar{P}_t (k^i_t - k^i_{t+1}) \geq 0, \quad \text{and} \quad k^i_t \geq 0.
\]

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

3.2 The continuation probability \( \pi \)

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.\(^{23}\)

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

\(^{22}\)In these linear induced utility treatments, \( \alpha^1 = 0.0122 \), \( \alpha^2 = 0.0161 \), and \( \delta^1 = \delta^2 = 0 \).

\(^{23}\)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)).
that assets continue to have value in future trading periods is \( \pi = \frac{5}{6} \).

Subjects are recruited for a three-hour session time, during which they participated in several “sequences,” each consisting of an indefinite number of three-minute “trading periods.” Each sequence of trading periods ended upon a die roll of 6. We chose to have subjects participate in several indefinite sequences to better familiarize them with the role played by the continuation probability \( \pi \). We instructed subjects that after one hour of play (following the reading of the instructions) the current sequence being played at that time would be the last one played; i.e., the next time a 6 is rolled the session came to a close. This design ensures a reasonable number of trading periods, while at the same time limiting 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. 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.

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, 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, \( k_i^t \), and the number of francs she has available for trade, \( y_i^t + \Delta k_i^t \). 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. 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

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\( ^24 \)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 \((\left( \frac{5}{6} \right)^{20} \approx 2.6\%) \) 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.

\( ^25 \)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.
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 other exclusions
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 Appendix C.\textsuperscript{26} 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.\textsuperscript{27} 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.

At the end of each period \( t \), subject \( i \)’s franc balance, \( s_i^t \) is declared for that period. The dollar
amount of this franc-consumption holding, \( u^i(s_i^t) \), accrues to her 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:

\textsuperscript{26}Copies of the instructions and materials are available at \url{http://www.socsci.uci.edu/~duffy/assetpricing/}.
\textsuperscript{27}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.
In this timeline, \( j \) indexes the transaction completed by subject \( i \) in period \( t \). \( P_{t,j} \) is the price governing the \( j \)th 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, \( s_t^i = Dk_t^i + y_t^i \). 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.

### 3.5 Subject risk preferences

Following completion of the last sequence of trading periods, beginning with Session 7 subjects are invited 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. 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 \( \{ \$0.30, \$4.80, \$6.00, \$11.55 \} \). All subjects agreed to participate in this second experiment. Appendix C includes the instructions for the Holt-Laury task.

### 3.6 Experimental Sessions

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

We began administering the Holt-Laury task following completion of the asset pricing experiment in sessions 7 through 20, after it became apparent to us it might help explain substantial variation in individual behavior 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%).

### 4 Experimental findings

We first report several summary statistics. Mean trading volume was similar between treatments (about 23 shares per period). Mean (median) allocative efficiency—earnings as a fraction of the

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28These 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.

29The Java script used to carry out the Holt-Laury test may be found at http://www.socsci.uci.edu/~duffy/assetpricing/.

30We also conduct a follow-up individual choice experiment, as described in Section 5.
maximum expected payoff at the fundamental price—averaged 0.73 (0.80) for the concave economies with no difference by dividend payment, while the linear economies are fully efficient by construction.

### 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 $P^*$ in 9 of 10 sessions.

To depict this visually, Figure 1 displays median transaction prices by period for the concave sessions, $\hat{D} = 2$ in Panel A and $\hat{D} = 3$ 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 $P^*$. For example, a price of -40% in Panel A, where $\hat{D} = 2$, reflects a price of 6, whereas a price of -40% in Panel B, where $\hat{D} = 3$, reflects a price of 9.

![Figure 1: Equilibrium-normalized Prices, Concave Sessions](image)

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 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 are sessions 8 and 9), but these “bubbles” are self-correcting by the end of the session.\footnote{Importantly, these corrections are wholly endogenous, rather than forced by a known finite horizon as in SSW. We emphasize that, while prices in the concave treatment lie at or below $P^*$, subjects are never informed of this fundamental trading price, as \textit{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.** \textit{In the concave utility treatments, there is strong evidence that subjects use the asset to intertemporally smooth their consumption.}

Figure 2 depicts the per capita shareholdings of type 1 subjects by period (per capita shares of type 3). 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, 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.

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 induced utility and not to the cyclic income process alone.

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 the 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

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32 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).

33 In this figure, the period numbers shown are aggregated over all sequences played. From a subject’s perspective, each sequence starts with period 1.
the comparative absence of 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 opti-
mal 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 implement the optimal consumption plan
and can observe transaction prices, we find strong evidence for consumption-smoothing.

4.2 Findings for induced linear utility

Finding 3. In the linear induced utility sessions ($\eta^i = 1$), on average trade in the asset occurs at
volumes similar to those observed in the concave sessions. Normalized transaction prices in the linear
utility sessions are significantly higher than prices in the concave utility sessions.

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).\footnote{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.}

Figure 4 displays median transaction prices by period for the linear sessions, $\overline{D} = 2$ in Panel A and $\overline{D} = 3$ 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.

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
$\overline{D} = 2$ or 3, in contradiction of 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
Table 3: Median Transaction Prices By Session and Treatment

corresponding induced concave utility treatment. Furthermore, Table 3 reveals the price difference between linear and concave treatments involving the same value of \( D \) generally diverges over time: The mean treatment price is monotonically \textit{increasing} in the linear treatments and generally \textit{decreasing} in the concave treatments. These trends at the session level can be identified using the Mann-Kendall \( \tau \) statistic, a non-parametric measure of monotonic trend.\textsuperscript{35} The \( \tau \) values and significance levels are reported in the last two columns of Table 3. Five of ten linear sessions have a significantly positive trend, 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 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

\textsuperscript{35}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.
for treatment differences in median prices during the final period of each session, as such prices best reflect learning and long-term trend in these markets.

We note first that, using a two-tailed Wilcoxon sign-rank test, we cannot reject the null hypothesis that the final period prices in treatments C2, C3, and L3 are equal to the risk-neutral steady state price, $P^*$, which was 10, 15 and 15, respectively ($p > .05$ for all three tests). However, we can reject the null hypothesis that the final period prices in treatment L2 equal the risk-neutral steady state price, $P^* = 10$ in favor of the alternative that these final prices were greater, ($p = .04$).

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.36 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 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, $D$.***

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, relative to a mean final price of 16 in L3. Thus, by the end of the experiment, prices indeed tended to be greater when $D = 3$ than when $D = 2$ (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)

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36 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).
initializes at a higher normalized price than every session in C3 (L3), which is statistically significant. This difference may be a consequence of the tighter budget constraint relative to the fundamental price for higher dividends\(^{37}\), or it could simply take time for subjects to develop an appreciation for the relation between dividend and asset value.

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 \(D = 3\) than for \(D = 2\), 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 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 by induced utility.\(^{38}\) 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

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\(^{37}\)The total value of shares at the fundamental price when \(D = 3\) is \(30 \times 15 = 450\) francs per period, while the total value of shares when \(D = 2\) is \(30 \times 10 = 300\) francs. The total quantity of francs available per period when \(D = 3\) is \(134 \times 6 + 30 \times 3 = 894\) francs, while the quantity when \(D = 2\) 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 \(D = 3\) but only 34% when \(D = 2\). 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, so it’s possible we could observe an analogous impact in our design.

\(^{38}\)We use the final sequence with a duration of at least two periods.
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 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. In autarky, the Gini coefficient is 0.3, the same value it takes 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.39

4.3 Findings for innate risk preferences

Our hypotheses imply that when subjects are intrinsically risk neutral, the observed price should be
$P^*$ in all treatments. Further, if subjects are characterized by strict DARA intrinsic utility, observed
prices should converge to $P^*$ in all treatments. Finally, if subjects are characterized by CARA intrinsic
utility, observed prices should be less than or equal to $P^*$. While we began our experiment under the
assumption that agents were intrinsically risk neutral with regard to uncertain money amounts, it
soon became apparent to us that this assumption might not be warranted and so, 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 $j \in \{1, 2, \ldots, 10\}$, 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

39Interestingly, 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.
(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.

To compare linear versus concave induced utility, we regress (OLS) a subject’s mean shareholdings during the final two periods of the session on the subject’s HL score for that session, with robust standard errors clustered on session-level observations. In the linear case, the estimated coefficient is 0.54 with p-value 0.0011 (Table B.1). Thus, a 1 standard deviation increase in the HL score (equal to 1.8 additional high-variance choices) results in a subject holding about 1 additional share of the asset by the end of the period. This is a significantly large impact, as there are only 2.5 shares per capita in these economies. On the other hand, in the concave case, the estimated coefficient is -0.159 with p-value 0.0853 (Table B.3), a marginally significant and relatively small negative impact. Thus, the HL score is a considerably more useful predictor of final shareholdings in the linear sessions. The more risk-tolerant (measured by HL score) a subject is, the more shares she tends to own by the end of a linear session. This result 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.*

As noted above, we conduct the Holt-Laury test only after the market experiment has concluded, as the latter 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 dummy variables indicating the treatment condition, ('linear' or 'D3') and on the individuals' earnings from the first—asset market—part of our experiment. 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 $P^*$, 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...

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40Since 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 33.6 with p-value 0.002 (Table B.2). Playing against the observed frequency of HL scores in all sessions, a risk-neutral subject with a score of 6 is predicted to hold 0.54 shares more than a subject with an HL score of 5, the same prediction as is obtained using the raw score approach. Other 1-score predicted differences range from 0.47 to 0.62 shares.
are greater than $P^*$ in 7 out of 10 sessions, contradicting Hypothesis 1 but consistent with the bubble prices reported by SSW (Hypothesis 2) that motivate 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 $P^*$. 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 $P^*$. One of the seven sessions has three risk-seeking subjects, yet the price in this session remains considerably lower than $P^*$ 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 $P^*$, and one ends below. Of the two high-price sessions, in one of them the risk-seeking subject ends the session holding 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 $\frac{Du^i(\pi)}{1-w^i(\pi)}$, and sell for a constant price greater than $\frac{Du^i(\pi)}{1-w^i(\pi)}$. Thus, it only takes one of twelve subjects with $w^i\left(\frac{5}{6}\right) > \frac{5}{6}$ (i.e., subject $i$ overweights $\pi$) to support prices greater than $P^*$. 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 \( P^* \). As previously mentioned in section 1, 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 have evidence to bear on this hypothesis, but see Haruvy et al. (2007) who 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 unlimited number of shares of the asset at an exogenously fixed price. 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. 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 budget constraint. We fixed the dividend on the asset to \( D = 2 \), so the risk-neutral fundamental price of the asset in all of these individual choice sessions is \( P^* = 10 \). A second treatment variable is the fixed price at which subjects can buy or sell the asset, \( P \in \{7, 10, 13\} \).

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. Both risk preferences and probability weighting may impact on behavior in this individual choice experiment. 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.

\[ ^{41} \text{We thank an anonymous referee for suggesting this treatment.} \]

\[ ^{42} \text{As prices are exogenous in our individual choice experiment, there is no need to have two player types.} \]

\[ ^{43} \text{Recall that mean prices in the concave market choice sessions average 24% below } P^*, \text{ while mean prices in the linear market choice experiments average 32% above } P^*. \text{ The two non-fundamental price treatments, (prices of 7 in the concave treatment (C2-7) or 13 in the linear treatment (L2-13) thus reflect the mean deviations we found in the market choice experiment.} \]

\[ ^{44} \text{Regarding the impact of probability weighting, consider a risk-neutral subject for whom } w^t(\pi = 5/6) = \frac{7}{8}. \text{ This subject will value one unit of the asset at 14 francs when } D = 2 \text{ (as opposed to the unweighted price of 10 francs). Thus, when facing a fixed price of 13 francs, this subject should optimally purchase as many shares as her budget constraint allows.} \]
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>
<thead>
<tr>
<th>Session</th>
<th>u (s)</th>
<th>D</th>
<th>Prices (# Subjects)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Concave</td>
<td>2</td>
<td>7 (6) 10 (6)</td>
</tr>
<tr>
<td>18</td>
<td>Concave</td>
<td>2</td>
<td>7 (6) 10 (6)</td>
</tr>
<tr>
<td>19</td>
<td>Concave</td>
<td>2</td>
<td>7 (6) 10 (6)</td>
</tr>
<tr>
<td>17-19</td>
<td>Concave</td>
<td>2</td>
<td>7 (18) 10 (18)</td>
</tr>
<tr>
<td>20</td>
<td>Linear</td>
<td>2</td>
<td>10 (6) 13 (6)</td>
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<tr>
<td>22</td>
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<td>2</td>
<td>10 (6) 13 (6)</td>
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<tr>
<td>20-22</td>
<td>Linear</td>
<td>2</td>
<td>10 (18) 13 (18)</td>
</tr>
</tbody>
</table>

Table 4: Individual choice sessions

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). We have thus have 18 independent observations for each of the four individual choice 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.

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. 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

45 The subjects in these individual choice sessions are University of Pittsburgh undergraduates who did not previously participate in any of our market choice experiments.
46 The instructions we use in these sessions are reported in Appendix C.
47 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.
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 7.** 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.

5.2 Trading volume

In the concave individual choice treatment with 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 (23), 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 8.** Trading volume is significantly larger with a fixed price of 7 as compared with 10 in the concave treatments, keeping the mean extent of consumption smoothing between treatments roughly constant.

In the linear sessions, \( \frac{u'(s_{t+1})}{u'(s_t)} = 1 \). Thus, when facing a constant price \( P \) and dividend \( D \), Equation (17) can be rearranged as \( \frac{U'(\zeta_{t+1})}{U'(\zeta_t)} = \frac{P}{\pi(P+D)} \). For an intrinsically risk-averse subject facing \( P \geq P^* \) as in L2-10 and L2-13, this expression implies \( \frac{U'(\zeta_{t+1})}{U'(\zeta_t)} \geq 1 \), which is infeasible since short sales are not permitted (recall \( \zeta_{t+1} = \zeta_t + c_{t+1} \)). Therefore, risk-averse subjects should sell all shares up front to maximize current consumption. However, few subjects “cash out” as predicted. Only 2 of 33 subjects whose IH score is less than 6 in the linear, fixed price of 10 (L2-10) treatment or less than 7 for linear, fixed price of 13 (L2-13) treatment actually hold zero shares throughout the session.\(^{48}\) However, mean trading volume at the higher price is nearly cut in half, from 3.9 shares per period at a price of 10 to 1.7 shares at a price of 13.\(^{49}\)

\(^{48}\)Even if we 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 5 of 33 subjects met this standard.

\(^{49}\)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.
Finding 9. In the linear treatments, mean trading volume more than doubled under the lower price. However, the behavior of few subjects (18%) is even loosely consistent with concave expected utility theory (that is, few subjects come even close to holding no shares throughout the session).

5.3 Innate 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 relationship 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 L-10 is positive and statistically significant. However, in the linear individual choice treatment L2-13, the relationship 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. 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. 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 groupings (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 market choice sessions, there is a significant difference when prices are high (p-value 0.0022).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Price</th>
<th>HL 1-4</th>
<th>HL 5-7</th>
<th>HL 8-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market</td>
<td>Low</td>
<td>2.19</td>
<td>3.01</td>
<td>3.83</td>
</tr>
<tr>
<td>Market</td>
<td>High</td>
<td>1.13</td>
<td>5.13</td>
<td>2.5</td>
</tr>
<tr>
<td>Choice</td>
<td>Low</td>
<td>3.14</td>
<td>5.13</td>
<td>NaN</td>
</tr>
<tr>
<td>Choice</td>
<td>High</td>
<td>2.07</td>
<td>2.17</td>
<td>NaN</td>
</tr>
</tbody>
</table>

Table 5: Mean Final Shares in Linear Individual Choice Sessions

**Finding 10.** 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 their demand for shares at far greater prices: those 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. However, we also find that prices
are not always equal to equilibrium values under the assumption that agents are intrinsically risk
neutral with regard to uncertain money earnings. Indeed, we find that prices in our induced concave
treatment are often below risk neutral equilibrium predictions. We rationalize these lower prices both
theoretically and empirically by accounting for subjects’ indigenous risk aversion. The latter findings
are 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 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.
References


Appendices

A Proofs

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

\[ v'(m_t) = (1 - \pi) U'(\zeta_t) u'(s_t^*). \] (24)

**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

\[ f(m_t, s_t^*(m_t)) = (1 - \pi) U(\zeta_t) + \pi \beta E_t[v(m_t+1)]. \] (25)

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

\[ \frac{df}{dm_t} = \frac{\partial f}{\partial m_t} + \frac{\partial f}{\partial s_t^*} \frac{ds_t^*}{dm_t}. \] (26)

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

\[ m_{t+1} = \frac{P_{t+1} + D_{t+1}}{P_t} (m_t + y_t - s_t). \] (27)

Thus,

\[ \frac{\partial f}{\partial m_t} = \pi \beta E_t \left[ v'(m_{t+1}) \frac{P_{t+1} + D_{t+1}}{P_t} \right]. \] (28)

Differentiating \( f \) with respect to \( s_t \) gives

\[ \frac{\partial f}{\partial s_t} = (1 - \pi) U'(\zeta_t) u'(s_t) - \pi \beta E_t \left[ v'(m_{t+1}) \frac{P_{t-1} + D_{t+1}}{P_t} \right]. \] (29)

By the first order condition in Equation (15), this expression is equal to zero. Thus, since \( \frac{df}{dm_t} = v'(m_t) \), by Equations (26) and (28),

\[ v'(m_t) = \pi \beta E_t \left[ v'(m_{t+1}) \frac{P_{t+1} + D_{t+1}}{P_t} \right]. \] (30)

Now, by the FOC in Equation (15),

\[ \pi \beta E_t \left[ v'(m_{t+1}) \frac{P_{t+1} + D_{t+1}}{P_t} \right] = (1 - \pi) U'(\zeta_t) u'(s_t). \] (31)

Therefore,

\[ v'(m_t) = (1 - \pi) U'(\zeta_t) u'(s_t). \]
### B Regression Results

Table B.1: OLS Regression of Final Shares on HL Scores, Linear (Clustered SEs)

\[ s_i = \beta_0 + \beta_1 h_i + \varepsilon_i \]

- \( s_i \) = average shares of subject \( i \) during the final 2 periods of the (linear) session
- \( h_i \) = HL score of subject \( i \) in the (linear) session

| Coefficient | Standard Error | \( z \) | \( P > |z| \) |
|-------------|----------------|--------|----------------|
| \( \beta_1 \) | 0.5435 | 0.1611 | 3.373 | 0.00114 |
| \( \beta_0 \) | 0.2612 | 0.6561 | 0.398 | 0.69161 |

Residual standard error: 3.317 on 82 degrees of freedom
Multiple R-squared: 0.08967, Adjusted R-squared: 0.07857
F-statistic: 11.38 on 1 and 6 DF, p-value: 0.01498

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 | \( z \) | \( P > |z| \) |
|-------------|----------------|--------|----------------|
| \( \beta_1 \) | 33.5725 | 10.5291 | 3.189 | 0.00203 |
| \( \beta_0 \) | -0.2977 | 0.9476 | -0.314 | 0.75418 |

Residual standard error: 3.279 on 82 degrees of freedom
Multiple R-squared: 0.1103, Adjusted R-squared: 0.09946
F-statistic: 10.17 on 1 and 82 DF, p-value: 0.002025
Table B.3: **OLS Regression of Final Shares on HL Scores, Concave (Clustered SEs)**

\[ s_i = \beta_0 + \beta_1 h_i + \epsilon_i \]

\[ s_i = \text{average shares of subject } i \text{ during the final 2 periods of the (concave) session} \]

\[ h_i = \text{HL score of subject } i \text{ in the (concave) session} \]

| Coefficient | Standard Error | \( z \) | \( P > |z| \) |
|-------------|---------------|--------|-------------|
| \( \beta_1 \) | -0.1590 | 0.0913 | -1.742 | 0.0853 |
| \( \beta_0 \) | 3.0755 | 0.3352 | 9.174 | 0.0000 |

Residual standard error: 1.879 on 82 degrees of freedom
Multiple R-squared: 0.02018, Adjusted R-squared: 0.008232
F-statistic: 3.034 on 1 and 6 DF, p-value: 0.1322

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

\[ h_i = \beta_0 + \beta_1 \text{Linear} + \beta_2 D3 + \beta_3 \pi_i + \epsilon_i \]

\[ h_i = \text{subject } i\text{'s Holt Laury score} \]

\[ \text{Linear: linear treatment dummy} \]

\[ D3: d = 3 \text{ treatment dummy} \]

\[ \pi_i = \text{subject } i\text{'s earnings} \]

<table>
<thead>
<tr>
<th>OLS Regression</th>
<th>Number of obs = 168</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R^2 ): 0.0196</td>
<td>F(3,13) = 0.85</td>
</tr>
<tr>
<td>Root MSE =1.8085</td>
<td>Prob &gt; F=0.4929</td>
</tr>
</tbody>
</table>

| \( h_i \) | Coef. | Std. Error | t | \( P > |t| \) | [95% Confidence Interval] |
|-----------|-------|------------|---|-------------|--------------------------|
| \( \beta_1 \) | 0.48265 | 0.34910 | 1.38 | 0.190 | [-0.2715289, 1.236823] |
| \( \beta_2 \) | -0.02579 | 0.32133 | -0.08 | 0.937 | [-0.7199748, 0.668395] |
| \( \beta_3 \) | 0.00606 | 0.02670 | 0.23 | 0.824 | [-0.0516208, 0.0637456] |
| \( \beta_0 \) | 3.54818 | 0.42785 | 8.29 | 0.000 | [2.623864, 4.472488] |
Table B.5: **OLS Regression of Final Shares on HL Scores, L10 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 | \( z \) | \( P > |z| \) |
|-------------|----------------|---------|-----------------|
| \( \beta_1 \) | 0.9306 | 0.4006 | 2.323 | 0.0337 |
| \( \beta_0 \) | 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, L13 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 | \( z \) | \( P > |z| \) |
|-------------|----------------|---------|-----------------|
| \( \beta_1 \) | -0.1923 | 0.6911 | -0.278 | 0.784 |
| \( \beta_0 \) | 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 Reg. 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 | \( z \) | \( P > |z| \) |
|-------------|---------------|--------|------------|
| \( \beta_1 \) | 0.3942 | 0.2440 | 1.615 | 0.113 |
| \( \beta_0 \) | 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 Reg. 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 | \( z \) | \( P > |z| \) |
|-------------|---------------|--------|------------|
| \( \beta_1 \) | 0.8129 | 0.3145 | 2.585 | 0.0142 |
| \( \beta_0 \) | -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
C Instructions

The instructions distributed to subjects in the C2 treatment are reproduced on the following pages. Subjects in the C3 treatment receive identical instructions, except that dividends were changed from 2 to 3 throughout. Subjects in the L2 and L3 treatments receive identical instructions to their counterparts in C2 and C3, respectively, except for the fourth paragraph. The modified fourth paragraph in the instructions for the L2 and L3 treatments is reproduced at the end of the C2 treatment instructions.

Following these instructions we present a reproduction of the endowment sheets, payoff tables, and payoff charts for all subjects. After these supplements we present the instructions distributed to all subjects for the Holt-Laury paired-choice lottery. Finally, we present instructions for the individual choice experiment. A complete set of all instructions used in all treatments of this experiment can be found at http://www.socsci.uci.edu/~duffy/assetpricing/.
Experimental Instructions [Treatment C2]

I. Overview. This is an experiment in the economics of decision making. If you follow the instructions carefully and make good decisions you may earn a considerable amount of money that will be paid to you in cash at the end of this session. Please do not talk with others for the duration of the experiment. If you have a question please raise your hand and one of the experimenters will answer your question in private.

Today you will participate in one or more “sequences”, each consisting of a number of “trading periods”. There are two objects of interest in this experiment, francs and assets. At the start of each period you will receive the number of francs as indicated on the page entitled “Endowment Sheet”. In addition, you will earn 2 francs for each unit of the asset you hold at the start of a period (please look at the endowment sheet now). During the period you may buy assets from or sell assets to other participants using francs. Details about how this is done are discussed below in section IV.

At the end of each period, your end-of-period franc balance will be converted into dollar earnings. These dollar earnings will accumulate across periods and sequences, and will be paid to you in cash at the end of the experiment. The number of assets you own carry over from one period to the next, if there is a next period (more on this below), whereas your end-of-period franc balance does not -you start each new period with the endowment of francs indicated on your Endowment Sheet. Therefore, there are two reasons to hold assets: (1) they provide additional francs at the beginning of each period and (2) assets may be sold for francs in some future period.

Please open your folder and look at the “Payoff Table” showing how your end-of-period franc balance converts into dollars. The “Payoff Chart” provides a graphical illustration of the payoff table. There are several things to notice. First, very low numbers of francs yield negative dollar payoffs. The lowest number in the payoff table is 11 francs. You are not permitted to hold less than 11 francs at any time during the experiment. Second, the more francs you earn in a period, the higher will be your dollar earnings for that period. Finally, the dollar payoff from each additional franc that you earn in a period is diminishing; for example, the payoff difference between 56 and 57 francs is larger than the difference between 93 and 94 francs.

NOTE: The total number of francs and assets held by all participants in this market does not change over the course of a sequence. Further, the number of francs provided by each asset, 2, is the same for all participants.
II. Preliminary Quiz

Using your endowment sheet and payoff table, we now pause and ask you to answer the following questions. We will come around to verify that your answers are correct.

1. Suppose it is the first period of a sequence (an odd-numbered period). What is the number of assets you own? ________________

2. What is the total number of francs you have available at the start of the first period, including both your endowment of francs and the 2 francs you get for each unit of the asset you own at the start of the period? ________________

3. Suppose that at the end of the first period you have not bought or sold any assets, so your franc total is the same as at the start of the period (your answer to question 2). What is your payoff in dollars for this first period? ________________

4. Suppose that the sequence continues with period 2 (an even-numbered period), and that you did not buy or sell any assets in the first period, so you own the same number of assets. What is the total number of francs you have available at the start of period 2, including both your endowment of francs and the 2 francs you get for each unit of the asset you own at the start of a period? ________________

5. Suppose again that at the end of period 2 you have not bought or sold any assets, so your franc total is the same as at the start of the period (your answer to question 4). What is your payoff in dollars for this second period? ________________ What would be your dollar earnings in the sequence to this point? ________________

III: Sequences of Trading Periods

As mentioned, today’s session consists of one or more “sequences,” with each sequence consisting of a number of “periods.” Each period lasts 3 minutes. At the end of each period your end-of-period franc balance, dollar payoff and the number of assets will be shown to you on your computer screen. One of the participants will then roll a die (with sides numbered from 1-6). If the number rolled is 1-5, the sequence will continue with a new, 3-minute period. If a 6 is rolled, the sequence will end and your cash balance for that sequence will be final. Any assets you own will become worthless. Thus, at the start of each period, there is a 1 in 6 (or about 16.7 percent) chance that the period will be the last one played in the sequence and a 5 in 6 (or about 83.3 percent) chance that the sequence will continue with another period.

If less than 60 minutes have passed since the start of the first sequence, a new sequence
will begin. You will start the new sequence and every new sequence just as you started the first sequence, with the number of francs and assets as indicated on your endowment sheet. The quantity of francs you receive in each period will alternate as before, between odd and even periods, and the total number of assets available for sale (across all participants) will remain constant in every period of the sequence. If more than 60 minutes has elapsed since the beginning of the first sequence then the current sequence will be the last sequence played; that is, the next time a 6 is rolled the sequence will end and the experiment will be over. The total dollar amount you earned from all sequences will be calculated and you will be paid this amount together with your $5 show-up fee in cash and in private before exiting the room.

If, by chance, the final sequence has not ended by the three-hour period for which you have been recruited, we will schedule a continuation of this sequence for another time in which everyone here can attend. You would be immediately paid your earnings from all sequences that ended in today’s session. You would start the continuation sequence with the same number of assets you ended with in today’s session, and your franc balance would continue to alternate between odd and even periods as before. You would be paid your earnings for this final sequence after it has been completed.

IV. Asset Trading Rules

During each three minute (180 second) trading period, you may choose to buy or sell assets. Trade happens on the trading window screen, show below. The current period is shown in the upper left and the time remaining for trading in this period (in seconds) is indicated in the upper right. The number of francs and assets you have available is shown on the left. Assets are bought and sold one unit at a time, but you can buy or sell more than one unit in a trading period.

To submit a bid or buying price for an asset, type in the amount of francs you are willing to pay for a unit of the asset in the “Buying price” box on the right. Then click on the “Post Buying Price” button on the bottom right. The computer will tell you if you don’t have enough francs to place a buy order; recall that you cannot go below a minimum of 11 francs in your account. Once your buy price has been submitted, it is checked against any other existing buy prices. If your buy price is higher than any existing buy price, it will appear under the “Buying Price” column in the middle right of the screen; otherwise, you will be asked to revise your bid upward - you must improve on existing bids. Once your buy price appears on the trading screen, any player who has a unit of the asset available can choose to sell it to you at that price.

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by using the mouse to highlight your buy price and clicking on the button “Sell at Highest Price” (bottom center-right of the screen). If that happens, the number of francs you bid is transferred to the seller and one unit of the asset is transferred from the seller to you. Another possibility is that another person will choose to improve on the buy price you submitted by entering a higher buy price. In that case, you must increase your buy price even higher to have a chance of buying the asset.

**Trading Window Screen**

To submit a selling or “ask” price for an asset, type in the amount of francs you would be willing to accept to sell an asset in the “Selling offer” box on the left and then click the “Post Selling Price” button on the bottom left. Note: you cannot sell an asset if you do not presently have an asset available to sell in your account. Once your sell price has been submitted, it is checked against any other existing sell prices. If your sell price is lower than any existing sell prices, it will appear on the trading screen under the ”Selling Price” column in the middle left of the screen; otherwise, you will be asked to revise your sell price downward - you must improve on existing offers to sell. Any participant who has enough francs available can choose to buy the asset from you at your price by using the mouse to highlight your sell price and
clicking on the button labeled “Buy at Lowest Price” (bottom center-left of the screen). If that happens, one unit of the asset is transferred from you to the buyer, and in exchange the number of francs you agreed to sell the asset for is transferred from the buyer to you. Another possibility is that another person will choose to improve on the sell price you submitted, by entering an even lower sell price. In that case, you will have to lower your sell price even further to have a chance of selling the asset.

Whenever an agreement to buy/sell between any two players takes place, the transaction price is shown in the middle column of the trading screen labeled “Transaction Price.” If someone has chosen to buy at the lowest price, all selling prices are cleared from the trading screen. If someone has chosen to sell at the highest price, all buying prices are cleared from the trading screen. As long as trading remains open, you can post new buy and sell prices and agree to make transactions following the same rules given above. The entire history of transaction prices will remain in the middle column for the duration of each trading period.

At the end of each period, you will be told your end-of-period franc balance and dollar payoff for the period, along with your cumulative total dollar payoff over all periods played in the sequence thus far. At then end of each sequence (whenever a “6” is rolled), we will ask you to write down, on your earnings sheet, the sequence number, the number of trading periods in that sequence and your total dollar payoff for that sequence.

V. Final Quiz

Before continuing on to the experiment, we ask that you consider the following scenarios and provide answers to the questions asked in the spaces provided. The numbers used in this quiz are merely illustrative; the actual numbers in the experiment may be quite different. You will need to consult your payoff table to answer some of these questions.

Question 1: Suppose that a sequence has reached period 15. What is the chance that this sequence will continue with another period - period 16? _______________. Would your answer be any different if we replaced 15 with 5 and 16 with 6? Circle one: yes / no.

Question 2: Suppose a sequence ends (a 6 is rolled) and you have n assets. What is the value of those n assets? _______________. Suppose instead, the sequence continued into another period (a 1-5 is rolled)-how many assets would you hold in the next period? _______________.

For questions 3-6 below: suppose at the start of this period you are given 70 francs. In addition, you own 3 assets.
Question 3: What is the maximum number of assets you can sell at the start of the 3-minute trading period? ________________.

Question 4: What is the total number of francs you will have available at the start of the trading period (including francs from assets owned)? ________________. If you do not buy or sell any assets during the 3-minute trading period, what would be your end-of-period dollar payoff? ________________.

Question 5: Now suppose that, during the 3-minute trading period, you sold 2 of your 3 assets: specifically, you sold one asset for a price of 4 francs and the other asset for a price of 8 francs. What is your end-of-period franc total in this case? ________________. What would be your dollar payoff for the period? ________________. What is the number of assets you would have at the start of the next period (if there is one)? ________________.

Question 6: Suppose that instead of selling assets during the trading period (as in question 5), you instead bought one more asset at a price of 18 francs. What would be your end-of-period franc total in this case? ________________. What would be your dollar payoff for the period? ________________. What is the number of assets you will have at the start of the next period (if there is one)? ________________.

VI. Questions

Now is the time for questions. If you have a question about any aspect of the instructions, please raise your hand.

What follows below is the fourth paragraph of the instructions for subjects in the L2 and L3 treatments.

Please open your folder and look at the “Payoff Table” showing how your end-of-period franc balance converts into dollars. The “Payoff Chart” provides a graphical illustration of the payoff table. There are several things to notice. First, the lowest number in the payoff table is 11 francs. You are not permitted to hold less than 11 francs at any time during the experiment. Second, the more francs you earn in a period, the higher will be your dollar earnings for that period. Finally, the dollar payoff from each additional franc that you earn in a period is the
same; the formula for converting between francs and dollars is fixed and is given at the bottom of your table.
This information is private. Please do not share with others.

Initial franc balance in all odd periods (first, third, fifth, etc.): **110**

Initial franc balance in all even periods (second, fourth, sixth, etc.): **44**

Assets you own in the first period: **1**

Francs paid per asset at start of each period: **2**

Therefore, you will begin the first period with **110 + 1*2 = 112** francs
This information is private. Please do not share with others.

Initial franc balance in all odd periods (first, third, fifth, etc.): 24

Initial franc balance in all even periods (second, fourth, sixth, etc.): 90

Assets you own in the first period: 4

Francs paid per asset at start of each period: 2

Therefore, you will begin the first period with $24 + 4 \times 2 = 32$ francs
This information is private. Please do not share with others.

Initial franc balance in all odd periods (first, third, fifth, etc.): \(110\)

Initial franc balance in all even periods (second, fourth, sixth, etc.): \(44\)

Assets you own in the first period: \(1\)

Francs paid per asset at start of each period: \(3\)

Therefore, you will begin the first period with \(110 + 1 \times 3 = 113\) francs
This information is private. Please do not share with others.

Initial franc balance in all odd periods (first, third, fifth, etc.): 24

Initial franc balance in all even periods (second, fourth, sixth, etc.): 90

Assets you own in the first period: 4

Francs paid per asset at start of each period: 3

Therefore, you will begin the first period with $24 + 4\times3 = 36$ francs
**PAYOFF TABLE**

How your end-of-period franc balance converts into dollar earnings

<table>
<thead>
<tr>
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The conversion formula is: Dollars = 2.6074 * 311.34^* (Frances - 1.195). If your end of period franc balance exceeds 130, we will use this formula to calculate your earnings.

Note: Your franc balance cannot fall below 11 francs.
[Type 1 subject, concave treatments (C2 and C3)]
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The conversion formula is: Dollars = $2.0627 \times 0.327.81^{(\text{Francs} \times 1.388)}$. If your end of period franc balance exceeds 130, we will use this formula to calculate your earnings. Note: Your franc balance cannot fall below 11 francs.
[Type 2 subject, concave treatments (C2 and C3)]
PAYOFF TABLE

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The conversion formula is: Dollars = 0.0122xFrancs. If your end of period franc balance exceeds 130, we will use this formula to calculate your earnings. Note: Your franc balance cannot fall below 11 francs.
[Type 1 subject, linear treatments (L2 and L3)]
## PAYOFF TABLE

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<th>64</th>
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<th>80</th>
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</table>

The conversion formula is: Dollars = 0.0161 × Francs. If your end of period franc balance exceeds 130, we will use this formula to calculate your earnings.

Note: Your franc balance cannot fall below 11 francs.
Type 2 subject, linear treatments (L2 and L3)
**Instructions** [Holt-Laury Paired Lottery Task]

You will face a sequence of 10 decisions. Each decision is a paired choice between two options, labeled “Option A” and “Option B”. For each decision you must choose either Option A or Option B. You do this by clicking next to the radio button corresponding to your choice on the computer screen. After making your choice, please also record it on the attached record sheet under the appropriate headings.

The sequence of 10 decisions you will face are as follows:

<table>
<thead>
<tr>
<th>Decision</th>
<th>Option A</th>
<th>Option B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive $6.00 10 out of 100 draws OR Receive $4.80 90 out of 100 draws</td>
<td>Receive $11.55 10 out of 100 draws OR Receive $ 0.30 90 out of 100 draws</td>
</tr>
<tr>
<td>2</td>
<td>Receive $6.00 20 out of 100 draws OR Receive $4.80 80 out of 100 draws</td>
<td>Receive $11.55 20 out of 100 draws OR Receive $ 0.30 80 out of 100 draws</td>
</tr>
<tr>
<td>3</td>
<td>Receive $6.00 30 out of 100 draws OR Receive $4.80 70 out of 100 draws</td>
<td>Receive $11.55 30 out of 100 draws OR Receive $ 0.30 70 out of 100 draws</td>
</tr>
<tr>
<td>4</td>
<td>Receive $6.00 40 out of 100 draws OR Receive $4.80 60 out of 100 draws</td>
<td>Receive $11.55 40 out of 100 draws OR Receive $ 0.30 60 out of 100 draws</td>
</tr>
<tr>
<td>5</td>
<td>Receive $6.00 50 out of 100 draws OR Receive $4.80 50 out of 100 draws</td>
<td>Receive $11.55 50 out of 100 draws OR Receive $ 0.30 50 out of 100 draws</td>
</tr>
<tr>
<td>6</td>
<td>Receive $6.00 60 out of 100 draws OR Receive $4.80 40 out of 100 draws</td>
<td>Receive $11.55 60 out of 100 draws OR Receive $ 0.30 40 out of 100 draws</td>
</tr>
<tr>
<td>7</td>
<td>Receive $6.00 70 out of 100 draws OR Receive $4.80 30 out of 100 draws</td>
<td>Receive $11.55 70 out of 100 draws OR Receive $ 0.30 30 out of 100 draws</td>
</tr>
<tr>
<td>8</td>
<td>Receive $6.00 80 out of 100 draws OR Receive $4.80 20 out of 100 draws</td>
<td>Receive $11.55 80 out of 100 draws OR Receive $ 0.30 20 out of 100 draws</td>
</tr>
<tr>
<td>9</td>
<td>Receive $6.00 90 out of 100 draws OR Receive $4.80 10 out of 100 draws</td>
<td>Receive $11.55 90 out of 100 draws OR Receive $ 0.30 10 out of 100 draws</td>
</tr>
<tr>
<td>10</td>
<td>Receive $6.00 100 out of 100 draws OR Receive $4.80 0 out of 100 draws</td>
<td>Receive $11.55 100 out of 100 draws OR Receive $ 0.30 0 out of 100 draws</td>
</tr>
</tbody>
</table>

After you have made all 10 decisions, the computer program will randomly select 1 of the 10 decisions and your choice for that decision will be used to determine your payoff. All 10 decisions have the same chance of being chosen.

Notice that for each decision, the two options describe two different amounts of money you can receive, depending on a random draw. The random draw will be made by the computer and will be a number (integer) from 1 to 100 inclusive. Consider Decision 1. If you choose Option A, then you receive $6.00 if the random number drawn is 10 or less, that is, in 10 out of 100 possible random draws made by the computer, or 10 percent of the time, while you receive $4.80 if the random number is between 11 and 100, that is in 90 out of 100 possible random draws made by the computer, or 90 percent of the time. If you choose Option B, then you receive $11.55 if the random number drawn is 10 or less, that is, in 10 out of 100 possible random draws made by the computer, while you receive $0.30
if the random number is between 11 and 100, that is in 90 out of 100 possible random draws made
by the computer, or 90 percent of the time. Other decisions are similar, except that your chances
of receiving the higher payoff for each option increase. Notice that all decisions except decision 10
involve random draws. For decision 10, you face a certain (100 percent) chance of $6.00 if you choose
Option A or a certain (100 percent) chance of $11.55 if you choose Option B.

Even though you make 10 decisions, only ONE of these decisions will be used to determine your
earnings from this experiment. All 10 decisions have an equal chance of being chosen to determine
your earnings. You do not know in advance which of these decisions will be selected.

Consider again decision 1. This will appear to you on your computer screen as follows:

The pie charts help you to visualize your chances of receiving the two amounts presented by each
option. When you are ready to make a decision, simply click on the button below the option you wish
to choose. Please also circle your choice for each of the 10 decisions on your record sheet. When you
are satisfied with your choice, click the Next button to move on to the next decision. You may choose
Option A for some decisions and Option B for others and you may change your decisions or make
them in any order using the Previous and Next buttons.

When you have completed all 10 choices, and you are satisfied with those choices you will need to
click the Confirm button that appears following decision 10. The program will check that you have
made all 10 decisions; if not, you will need to go back to any incomplete decisions and complete those
decisions which you can do using the Previous button. You can also go back and change any of your
decisions prior to clicking the confirm button by using the Previous button.

Once you have made all 10 decisions and clicked the Confirm button, the results screen will tell you
the decision number 1, 2, . . . 10, that was randomly selected by the computer program. Your choice
of option A or B for that decision (and that decision only) will then be used to determine your dollar payoff. Specifically, the computer will draw a random number between 1 and 100 (all numbers have an equal chance) and report to you both the random number drawn and the payoff from your option choice.

Your payoff will be added to the amount you have already earned in today’s experiment. Please circle the decision that was chosen for payment on your record sheet and write down both the random number drawn by the computer program and the amount you earned from the option you chose for that decision on your record sheet. On the computer monitor, type in your subject ID number, which is the same number used to identify you in the first experiment in today’s session. Then click the "Save and Close" button.

Are there any questions before we begin?

Please do not talk with anyone while these decisions are being made. If you have a question while making decisions, please raise your hand.
<table>
<thead>
<tr>
<th>Decision</th>
<th>Circle Option Choice</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision 1</td>
<td>A B</td>
<td></td>
</tr>
<tr>
<td>Decision 2</td>
<td>A B</td>
<td></td>
</tr>
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<td>A B</td>
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<td></td>
</tr>
<tr>
<td>Decision 10</td>
<td>A B</td>
<td></td>
</tr>
</tbody>
</table>

At the end of this experiment, circle the Decision number selected by the computer program for payment. Write down the random number drawn for the selected decision (between 1 and 100):

________________________ Write down your payment earned for this part of the experiment: $________________________
Experimental Instructions [Treatments C2-7 and C2-10]

I. Overview.

This is an experiment in the economics of decision making. If you follow the instructions carefully and make good decisions you may earn a considerable amount of money that will be paid to you in cash at the end of this session. Please do not talk with others for the duration of the experiment. If you have a question please raise your hand and one of the experimenters will answer your question in private.

Today you will participate in one or more “sequences”, each consisting of a number of “trading periods”. There are two objects of interest in this experiment, francs and assets. At the start of each period you will receive the number of francs as indicated on the page entitled “Endowment Sheet.” In addition, you will earn a “dividend” of 2 francs for each unit of the asset you hold at the start of a period (please look at the endowment sheet now). During the period you may buy or sell assets using francs at the price listed on the endowment sheet. Details about how this is done are discussed below in section IV.

At the end of each period, your end-of-period franc balance will be converted into dollar earnings. These dollar earnings will accumulate across periods and sequences, and will be paid to you in cash at the end of the experiment. The number of assets you own carry over from one period to the next, if there is a next period (more on this below), whereas your end-of-period franc balance does not you start each new period with the endowment of francs indicated on your Endowment Sheet. Therefore, there are two reasons to hold assets: (1) they provide additional francs at the beginning of each period and (2) assets may be sold for francs in some future period.

Please open your folder and look at the “Payoff Table” showing how your end-of-period franc balance converts into dollars. The “Payoff Chart” provides a graphical illustration of the payoff table. There are several things to notice. First, very low numbers of francs yield negative dollar payoffs. The lowest number in the payoff table is 11 francs. You are not permitted to hold less than 11 francs at any time during the experiment. Second, the more francs you earn in a period, the higher will be your dollar earnings for that period. Finally, the dollar payoff from each additional franc that you earn in a period is diminishing; for example, the payoff difference between 56 and 57 francs is larger than the difference between 93 and 94 francs.
II. Preliminary Quiz

Using your endowment sheet and payoff table, we now pause and ask you to answer the following questions. We will come around to verify that your answers are correct.

1. Suppose it is the first period of a sequence (an odd-numbered period). What is the number of assets you own? ________________

2. What is the total number of francs you have available at the start of the first period, including both your endowment of francs and the 2 francs you get for each unit of the asset you own at the start of the period? ________________

3. Suppose that at the end of the first period you have not bought or sold any assets, so your franc total is the same as at the start of the period (your answer to question 2). What is your payoff in dollars for this first period? ________________

4. Suppose that the sequence continues with period 2 (an even-numbered period), and that you did not buy or sell any assets in the first period, so you own the same number of assets. What is the total number of francs you have available at the start of period 2, including both your endowment of francs and the 2 francs you get for each unit of the asset you own at the start of a period? ________________

5. Suppose again that at the end of period 2 you have not bought or sold any assets, so your franc total is the same as at the start of the period (your answer to question 4). What is your payoff in dollars for this second period? ________________ What would be your dollar earnings in the sequence to this point? ________________

III: Sequences of Trading Periods

As mentioned, today’s session consists of one or more “sequences,” with each sequence consisting of a number of “periods.” Each period will last approximately 2 minutes. At the end of each period your end-of-period franc balance, dollar payoff and the number of assets will be shown to you on your computer screen. One of the participants will then roll a die (with sides numbered from 1-6). If the number rolled is 1-5, the sequence will continue with a new, 3-minute period. If a 6 is rolled, the sequence will end and your cash balance for that sequence will be final. Any assets you own will become worthless. Thus, at the start of each period, there is a 1 in 6 (or about 16.7 percent) chance that the period will be the last one played in
the sequence and a 5 in 6 (or about 83.3 percent) chance that the sequence will continue with another period.

If fewer than 14 total periods have occurred in this experiment, a new sequence will begin. You will start the new sequence and every new sequence just as you started the first sequence, with the number of francs and assets as indicated on your endowment sheet. The quantity of francs you receive in each period will alternate as before, between odd and even periods. If at least 14 periods have taken place since the start of the experiment, then the current sequence will be the last sequence played; that is, the next time a 6 is rolled the sequence will end and the experiment will be over. The total dollar amount you earned from all sequences will be calculated and you will be paid this amount together with your $5 show-up fee in cash and in private before exiting the room.

If, by chance, the final sequence has not ended by the three-hour period for which you have been recruited, we will schedule a continuation of this sequence for another time in which everyone here can attend. You would be immediately paid your earnings from all sequences that ended in today’s session. You would start the continuation sequence with the same number of assets you ended with in today’s session, and your franc balance would continue to alternate between odd and even periods as before. You would be paid your earnings for this final sequence after it has been completed.

IV. Asset Trading Rules

You will make your decision to buy or sell assets by entering information into the Pre-Trade Window, an example of which is presented below. The current sequence appears in the upper-left corner of the screen, the current period number in the right. The next four lines within the window provide you with information regarding your franc and asset position at the beginning of the period. For example, in the window below, you would begin the current period with an endowment of 110 francs and 1 unit of the asset. Since each unit of the asset pays an additional 2 francs, your total available francs to start the period would be 112.

Below this information you are reminded of the price of each unit of the asset (in this example the price is 10 francs, but the price you will actually use is presented on your Endowment Sheet), and you are asked to decide whether you’d like to buy or sell units of the assets at this price. In the example below, the “Buy” button has been selected. After you have decided whether
you will be a buyer or a seller, you will enter how many units of the asset you’d like to trade. Recall that you cannot sell a greater quantity of assets than you currently possess, and that you cannot buy so many units of the asset that your current franc balance would drop below 11. If you would like to trade nothing in this period, choose the Buy or Sell button (it doesn’t matter which one) and enter a quantity of 0. Once you have entered your desired quantity, click the red “OK” button to complete the transaction. When you click this button, your decision is final.

### Pre-Trade Window

<table>
<thead>
<tr>
<th>Sequence 1</th>
<th>Period 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your endowment of francs this period:</td>
<td>110</td>
</tr>
<tr>
<td>Your current asset holdings:</td>
<td>1,00</td>
</tr>
<tr>
<td>Your total dividends this period:</td>
<td>2,00</td>
</tr>
<tr>
<td>Your total available franc balance:</td>
<td>112,00</td>
</tr>
</tbody>
</table>

You can choose to buy or sell assets this period. The price of an asset is 10 francs.

- **Buy**
- **Sell**

Please select "Buy" or "Sell".

After you have made your trading decision, you will be presented with a new window, as depicted in the *Post-Trade Window* below. In this example, you have made the decision to buy two units of the asset. Since you started the period with 112 francs, and since assets cost 10 francs each, you would end the period with $112 - 10 \times 2 = 92$ francs and 3 units of the asset (recall that you started the period with one unit). Your dollar payoff for the period, based on your end-of-period franc balance of 92 francs, would be $1.21$ (you can confirm this amount on your Payoff Table). Your cumulative earnings over all periods in the current sequence are also displayed.

### Post-Trade Window

After all of the experiment participants have clicked the OK button, the die
will be rolled to determine if the sequence will continue. On a roll of 1-5, the sequence will continue. You would begin the next period of the sequence with your endowment income (in the example above, you would begin period 2 with endowment income of 44 francs, as stated on your Endowment Sheet), dividend income (in this example 6 francs, because you hold 3 units of the asset, and each unit pays a dividend of 2 francs), and your assets from the previous period (in this example, 3 units). On a roll of “6” the sequence is over, in which case we will ask you to write down, on your Earnings Sheet, the sequence number, the number of trading periods in that sequence and your total dollar payoff for that sequence.

V. Final Quiz

Before continuing on to the experiment, we ask that you consider the following scenarios and provide answers to the questions asked in the spaces provided. The numbers used in this quiz are merely illustrative; the actual numbers in the experiment may be quite different. You will need to consult your payoff table to answer some of these questions.

Question 1: Suppose that a sequence has reached period 15. What is
the chance that this sequence will continue with another period - period 16? ____________. Would your answer be any different if we replaced 15 with 5 and 16 with 6? Circle one: yes / no.

Question 2: Suppose a sequence ends (a 6 is rolled) and you have \( n \) assets. What is the value of those \( n \) assets? ____________. Suppose instead, the sequence continued into another period (a 1-5 is rolled) – how many assets would you hold in the next period? ____________.

For questions 3-6 below: suppose at the start of this period you are given 70 francs. In addition, you own 3 assets.

Question 3: What is the maximum number of assets you can sell in the trading period? ____________.

Question 4: What is the total number of francs you will have available at the start of the trading period (including francs from assets owned)? ____________. If you do not buy or sell any assets during the trading period, what would be your end-of-period dollar payoff? ____________.

Question 5: Now suppose that you sold 2 of your 3 assets during the trading period at a price of 8 francs. What is your end-of-period franc total in this case? ____________. What would be your dollar payoff for the period? ____________. What is the number of assets you would have at the start of the next period (if there is one)? ____________.

Question 6: Suppose that instead of selling assets during the trading period (as in question 5), you instead bought one more asset at a price of 18 francs. What would be your end-of-period franc total in this case? ____________. What would be your dollar payoff for the period? ____________. What is
the number of assets you will have at the start of the next period (if there is one)? ____________.

VI. Questions

Now is the time for questions. If you have a question about any aspect of the instructions, please raise your hand.