Asset Pricing Experiments: Bubbles, Crashes & Expectations

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Asset Price Bubbles

- A bubble is difficult to define, but it involves seemingly irrational behavior and is manifested by a sustained departure of the price of an asset from underlying fundamentals.

- Bubbles are typically viewed as unsustainable, though examples of stationary bubbles, e.g. fiat money, have been provided (Tirole *Ecmta* 1985).

- The supposed irrationality underlying asset price bubbles has been thoroughly questioned, as it challenges the efficient markets hypothesis. This has led to theories of rational bubbles.

- However, as these rational bubble theories appear at odds with the actual volatility in asset prices, as well as with laboratory evidence showing that individuals are not invariant to the decision-frame, a new behavioral finance literature has emerged to challenge the conventional view of asset pricing.

Rational Bubbles

- Perhaps the main theory of bubbles is the rational bubble theory.
- Define the gross rate of return on an asset

$$R_{t+1} = \frac{p_{t+1} + d_{t+1}}{p_t}$$

so the net return $r_{t+1} = R_t - 1$, with p_t being the price in period t and d_t the dividend.

- Rearranging and taking expectations conditional on date t information, we have

$$p_t = \frac{E_t(p_{t+1} + d_{t+1})}{1 + E_t(r_{t+1})}$$

- Assuming rational expectations and that $E_t(r_{t+1}) = r$, the rate of time preference, we can write:

$$p_t = (1 + r)^{-1} E_t(d_{t+1} + p_{t+1}). \tag{1}$$

Rational Bubbles, Continued

- Using the law of iterated expectations, we can expand the price equation as:

$$p_t = \sum_{i=1}^{n} (1+r)^{-i} E_t(d_{t+i}) + (1+r)^{-n} E_t(p_{t+n}).$$

- Taking the limit as n goes to infinity:

$$p_t = \sum_{i=1}^{\infty} (1+r)^{-i} E_t(d_{t+i}) + \lim_{n \to \infty} (1+r)^{-n} E_t(p_{t+n}),$$

assuming the limit exists. Call the first term the fundamental component f_t and the second term the bubble component, b_t,

$$p_t = f_t + b_t \tag{2}$$

Properties of Rational Bubbles

- Substitute (2) into (1):

$$f_t + b_t = (1+r)^{-1} E_t(d_{t+1} + f_{t+1} + b_{t+1})$$

- Using the definition of f_t:

$$\sum_{i=1}^{\infty} (1+r)^{-i} E_t(d_{t+i}) + b_t \;=\; (1+r)^{-1} E_t(d_{t+1}) +$$

$$\sum_{i=2}^{\infty} (1+r)^{-i} E_t(d_{t+i}) + (1+r)^{-1} E_t(b_{t+1})$$

$$\text{or} \quad b_t \;=\; (1+r)^{-1} E_t(b_{t+1})$$

Rational bubbles grow at the same rate as fundamentals: if $b > 0$, prices grow exponentially.

- Rational bubbles can occur only in models with an infinite horizon, otherwise by backward induction $b_T = 0$ implies $b_t = 0 \forall t$!
- If there is a constant probability that a bubble will burst it must grow at an even faster rate to compensate. (Blanchard and Watson 1982).

Bubbles in the Laboratory?: Non-rational bubbles

- Smith Suchaneck and Williams (SSW, *Ecmta* 1988) experimental design reliably generates asset price bubbles and crashes in a *finite horizon* economy, thus ruling out *rational* bubble stories.
- T trading periods (typically $T = 15$) and 9-12 inexperienced subjects.
- Each subject is initially endowed with various amount of cash and assets. Assets are long-lived (T periods). Endowments, are ex-ante identical in expected value -there is no reason for trade!
- In each trading period, agents are free to buy or sell the asset. Trade takes place via a double auction, and bids and asks must obey standard improvement rules.
- For each unit of the asset held at the end of a trading period, the asset owner earns a dividend payment which is a uniform draw from a known distribution and has mean $\overline{d}$.
- It is public knowledge that the fundamental value of an asset at the start of period t is given by: $D_t^T = \overline{d}(T - t + 1) + D_{T+1}^T$.

An Specific Parameterization (SSW Design #2)

**Table 1.** Smith et al. (1988) Experimental design 2

Players	Endowment (cash, quantity)	Number of players
Class I	($2.25; 3)	3
Class II	($5.85; 2)	3
Class III	($9.45; 1)	3
Dividends	$d \in \{\$0, \$0.04, \$0.14, \$0.20\}$[a] $\overline{d} = 0.12$	
Initial value of a share	$\overline{D}_1^T$[b] = $3.60	
Buy-out value of a share	$D_{T+1}^T = \$1.80$	

[a] Each dividend outcome occurs with probability $\frac{1}{4}$.
[b] Each period's expected fundamental value is denoted by $\overline{D}_t^T$ for $t = 1, ..., T + 1$. These values were calculated and displayed on the screen in each trading period in the human subject experiments.

Payoff = initial endowment of money+dividends on assets held+money received from sales of shares- the money spent on purchases of shares+buyout value.
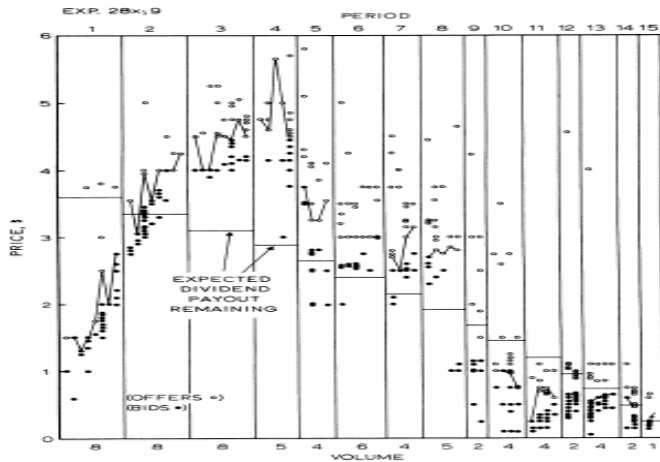
Data Analysis
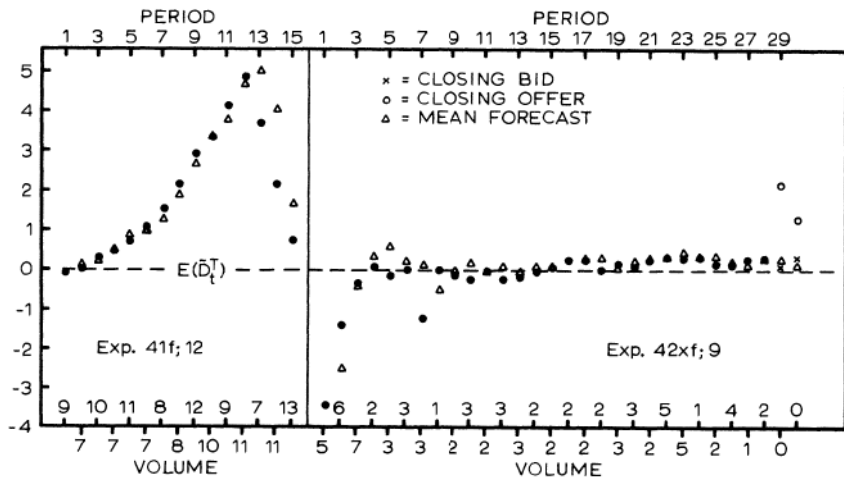
There is a substantial volume of bids, asks and trading volume in this type of experiment

- Smith et al. analyze a price adjustment dynamic of the form:

$$\overline{P}_t - \overline{P}_{t-1} = \alpha + \beta(B_t - O_t)$$

where $\overline{P}_t$ is mean traded price in period t, B_t is the number of bids in period t and O_t is the number of asks in period t.

- The rational, efficient markets hypothesis is that $\alpha = -E_t d_t$ and $\beta = 0$, i.e., that subjects are trading according to fundamentals.

- Empirically, Smith et al. report that they cannot reject that hypothesis that $\alpha = -E_t d_t$ but they do find that β is significantly positive: $B_t - O_t$ captures variations in aggregate demand, which affects prices.

- Conclude that a common dividend and common knowledge of it are insufficient to generate common expectations among inexperienced subjects.

Robustness of Laboratory Bubbles?

- Smith et al. (*ET* 2000) show that the bubble crash pattern persists if dividends are eliminated, and there is only a final buy-out value.

- Noussair et al. (*EE* 2001) show that bubbles continue to emerge if there is a constant (non-decreasing) dividend value. They suppose that dividends are a uniform random draw from the set $\{-.03, \ -.02, \ 0.005, \ 0.045\}$, so $\overline{d} = 0$. They report that in 4 out of 8 sessions, they get a bubble crash pattern as in the Smith et al. design.

- Dufwenberg et al. (*AER* 2005) show that adding just a small fraction of experienced traders - $1/3$ with $2/3$ inexperienced leads to a near elimination of bubbles.

- Haruvy and Noussair (*JFin* 2006) argue that the restriction on short-sales may lie behind departures from fundamentals. In the absence of short sales, a trader's ability to speculate on downward price movements is limited to the sale of all the assets he owns. They find that relaxing short-sale restrictions can reduce prices.

Lei et al. (*Ecmta* 2001)

- Explore the boredom/experimenter demand hypothesis
- They consider two main treatment variables.
  - No-Spec treatment: Buyers and Sellers have distinct roles. In particular, a buyer cannot resell his asset later in a 2-minute trading period at a higher price. This tests the greater-fool hypothesis that speculation is driving the results.
  - Two-Market treatment: Two markets operate simultaneously. One is for a one-period asset Y; holders of this asset sell it to buyers in fixed roles. The other market is the standard 15-period asset of the laboratory bubble design; this asset could be traded (bought and sold) by all subjects.
- Main finding, neither treatment completely eliminates bubbles and crashes. Trading volume is much lower in the two-market treatment as compared with the standard one-market case.

Haruvy et al. (*AER* 2007)
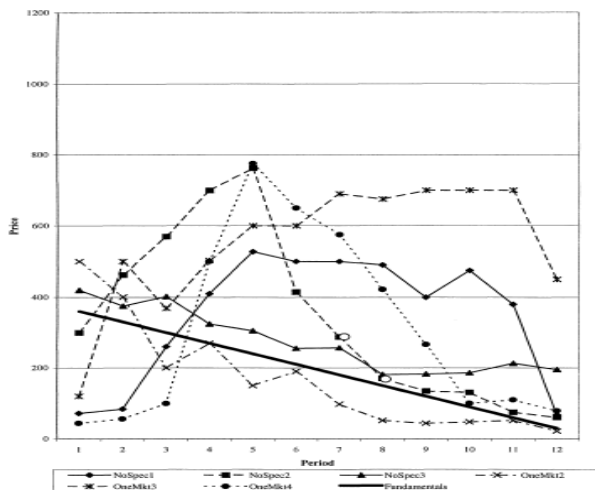
- Look at role of long-term expectations in the SSW design.
- At the start of each trading period, $t < T = 15$, elicit trader's expectations of market prices in all remaining $T-t+1$ periods.
- Used a call-market institution, a sealed-bid version of a double auction: each trader can submit a buy or sell price and a quantity to buy/sell. Bids are ranked from highest to lowest, asks from lowest to highest and a single market price is determined.
- 9 Subjects participate together in 4, 15-period "markets" (replications).
- Subjects were paid both for trades and correct market price predictions.
- Clear evidence that inexperienced subjects have incorrect beliefs about the correspondence between prices and fundamentals.
- Price predictions are adaptive: market peaks consistently occur earlier than traders predict.

Prices and Beliefs About Prices
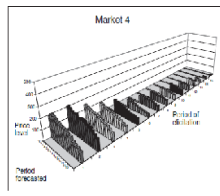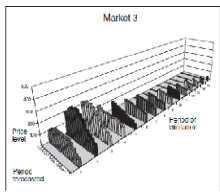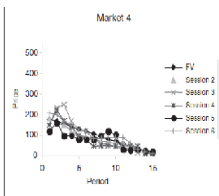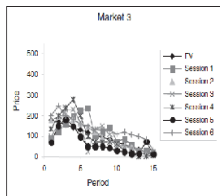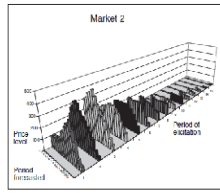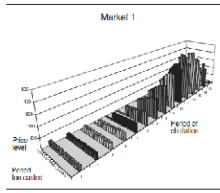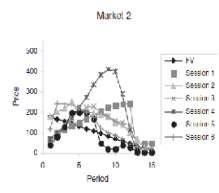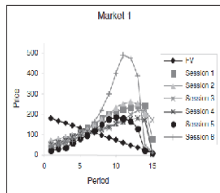
Repeated Bubbles and Crashes with Experienced Subjects?

- Hussam et al. *AER* 2008 argue that repeated bubbles among experienced subjects requires a change in the asset environment as might arise e.g., from a technological revolution.
- They first run 5 cohorts of 9-12 subjects through a standard SSW experimental design.
- In a new "rekindle" treatment, they take once-experienced subjects and: 1) randomly divide them into 3 new groups (so group composition is altered). They also 2) increase the mean and variance of the dividend process – the support changes from {0, 8, 28, 60} to {0,1,28,98} and finally 3) they cut initial share endowments in half and double the initial cash positions of the three player types.
- This rekindle treatment is compared with a standard "twice-repeated" treatment with no change in the subject population, dividend process or initial conditions.

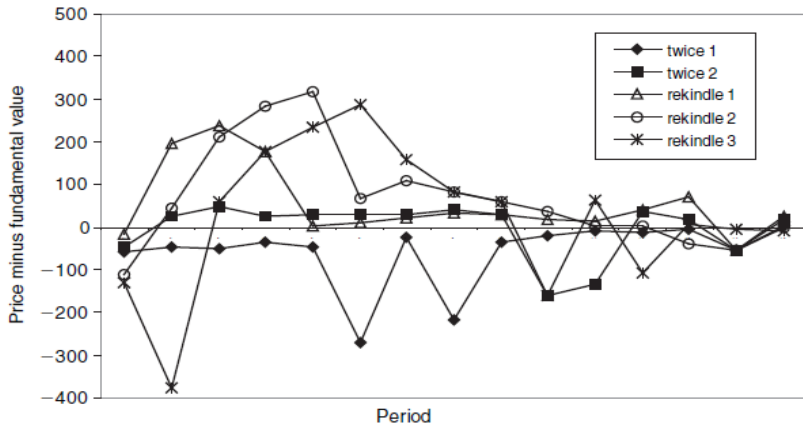# Shocking the system leads to bubbles among experienced subjects

FIGURE 4. TIME SERIES PRICE DEVIATION FROM FUNDAMENTAL VALUE FOR THE REKINDLE AND TWICE-EXPERIENCED BASELINE REPLICATION

A Forecasting Game Approach to Asset Pricing (Hommes et al. 2005)

- 6 subjects seek to forecast the price of an asset. They can condition on past prices (except for the first period).
- The dividend per unit of asset is a known constant $\overline{d}$ (alternatively, can be stochastic with known distribution).
- No other task: given the 6 forecasts, actual prices are determined by a computer program using

$$p_t = \frac{1}{1+r} \left(\frac{1}{6} \sum_{i=1}^{6} p_{i,t+1}^e + \overline{d} + \epsilon_t \right).$$

where ϵ_t is a mean zero stochastic process.

- This is a pure test of expectation formation; no confounding effects from trading behavior.
- Payoffs are according to forecast accuracy.
- Rational expectation prediction is $p_t = \overline{d}/r + \epsilon_t/r$.

Findings

- Monotonic and Oscillatory Convergence/Divergence are all observed.
- Often there is excess volatility relative to ϵ which is very small.
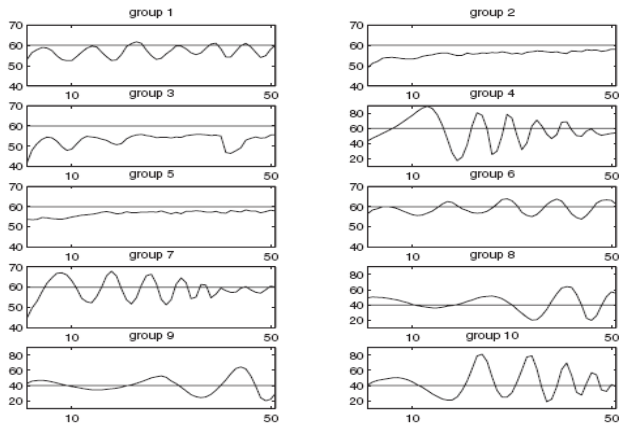
Summary

- Participants who succeed in predicting average opinion well perform well in this experiment.
- This feature may be similar to real asset markets and is support for Keynes' famous beauty contest analogy.
- Subjects are rather successful in anticipating what "average opinion expects average opinion to be."
- They also consider a variant where some fraction of traders are programmed to predict the fundamental price in every period; this further helps convergence to some degree.
- But restriction of prices to (0,100), though this range includes the fundamental price, rules out rational bubbles.

A Consumption Smoothing GE Approach (Crockett and Duffy 2010)

- Assets are potentially long-lived and pay a common dividend (in terms of francs)
- Francs (consumption) converted into dollars each period and then disappear.
- Infinite horizon, implemented as a constant probability of continuation of a sequence of trading periods.
- We induce a utility function on subjects (the franc-to-dollar exchange rate) that is either concave or linear.
- If concave, there is an induced (smoothing) incentive for trade in the asset; If linear, there is no induced incentive for trade in the asset.
- We find asset under-pricing (relative to the expected value) in the concave utility treatment, and asset bubbles in the linear utility treatment.

Model

- The representative agent of type i seeks to maximize:

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

  subject to

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

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

$$p_t = \beta E_t \left[\frac{u'(c_{t+1})}{u'(c_t)} (p_{t+1} + \overline{d}) \right].$$

- Steady state equilibrium price: $p^* = \frac{\beta}{1-\beta} \overline{d}$. Same for both the concave and linear treatments.

Within-period Sequencing

The timing of activity is summarized below:

- Begin period t.
- Income and dividends paid.
- Assets traded (3-minute double auction)
- Random draw against β determined by die roll.
- Begin period $t + 1$, if applicable.

The set of periods that comprise the "life" of a given asset is called a *sequence*. We run several sequences per session.

Endowments and Treatments

Endowments

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

2×2 Treatment Design

	$\bar{d} = 2$	$\bar{d} = 3$
Concave $\phi^i < 1$ and $\alpha^i \phi^i > 0$	**C2** 4 sessions	**C3** 4 sessions
Linear $\phi^i = 1$	**L2** 4 sessions	**L3** 4 sessions

Steady State Competitive Equilibrium Benchmarks

- $\bar{d} = 2$
  - $p^* = 10$
  - Type 1 shares cycle between 1 (4) in odd (even) periods
  - Type 2 shares cycle between 4 (1) in odd (even) periods

- $\bar{d} = 3$
  - $p^* = 15$
  - Type 1 shares cycle between 1 (3) in odd (even) periods
  - Type 2 shares cycle between 4 (2) in odd (even) periods

Holt-Laury Paired Choice Lottery

Beginning with session 7, subjects faced Holt-Laury (2002) paired-lottery task after the asset market experiment.

- Ten choices between two lotteries, A and B.
- A paid \$6 or \$4.80, B paid \$11.55 or \$0.30.
- In choice $n \in 1, 2, ...10$, the probability of receiving the high payoff was $0.1 * n$
- One choice was chosen for payment at random.
- Risk-neutral subject would choose B six times.
- 16% of subjects chose B at least six times, 30% chose B at least five times, mean number of B choices was 3.9 (a common frequency in the literature) which implies a Coeff of RRA $0.41 < r < 0.68$ (moderate risk aversion).

Price Results

Finding 1: In the concave utility treatment ($\phi^i < 1$), observed transaction prices at the end of the session are generally less than or equal to $p^* = \frac{\beta}{(1-\beta)}\bar{d}$.

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Finding 2: In the linear induced utility sessions ($\phi^i = 1$) trade in the asset does occur, at volumes similar to the concave sessions. Observed transaction prices are significantly higher in the linear sessions.
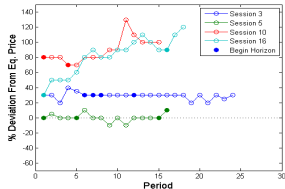
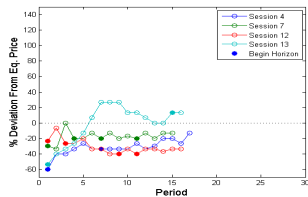# Median Equilibrium-Normalized Prices
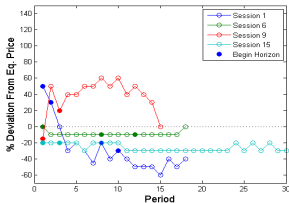
Concave, d=2
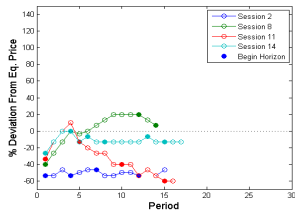
Concave, d=3

Linear, d=2

Linear, d=3

Prices Across Treatments

	Mean	First Pd	Final Half	Final 5 Pds	Final Pd	Forecast	Change	Prob
C2	**9.4**	**10.4**	**8.9**	**8.8**	**8.3**			
S1	7.1	15.0	5.5	5.2	6.0	6.8	0.61	0.31
S6	9.1	10.0	9.1	9.2	10	9.7	0.16	0.27
S9	13.8	8.5	13.9	13.2	10.0	9.6	-1.48	0.87
S15	7.4	8	7.2	7.4	7.0	7.5	0.07	0.43
C3	**11.6**	**9.3**	**11.4**	**11.2**	**10.8**			
S2	7.5	7.0	7.4	7.4	8.0	7.5	-0.01	0.50
S8	15.4	9.0	17.4	17.4	16.0	15.7	-0.80	0.91
S11	10.2	10.0	7.6	6.8	6.0	3.9	-1.01	0.73
S14	13.2	11.0	13.1	13.2	13.0	12.6	-0.18	0.58
L2	**15.0**	**13.5**	**15.8**	**16.0**	**16.5**			
S3	12.9	13.0	12.8	12.7	13.0	12.5	-0.05	0.56
S5	10.0	10.0	9.9	10.2	11.0	10.6	0.18	0.36
S10	18.9	18.0	20.3	20.8	20.0	21.4	0.38	0.38
S16	18.2	13.0	20.0	20.2	22.0	20.7	0.00	0.50
L3	**12.0**	**8.8**	**12.5**	**12.6**	**13.3**			
S4	10.3	6.0	11.2	11.7	13.0	12.0	0.11	0.45
S7	12.3	10.5	12.5	12.6	13.0	12.4	-0.12	0.54
S12	10.4	11.5	9.7	9.9	10.0	10.5	0.33	0.35
S13	14.8	7.0	16.6	16.0	17.0	13.5	-1.29	0.78

Focus on final prices

- Why? Rather complicated environment with potential for substantial learning.
- During the second half of sessions:
  - Concave treatment prices trended flat or down
  - Linear treatment prices trended flat or up.
- Final prices therefore best reflect learning and long-term trends.

Analysis of Price Differences

- Pooling by linear vs. concave, linear sessions finished 27% above fundamental price on average, concave sessions 23% below (p-value 0.0350).

  - Difference is still large (+21% vs. -18%) over second half of each session, but p-value is 0.1412.

- L2 is significantly different from all other treatments, the others are not significantly different from each other.

- L3 prices actually increased more than L2 prices during session on average (4.5 vs. 3 francs).
- Thus the difference is due to a large difference in initial prices (13.5 vs. 8.75 on average).

Why large difference between L2 and L3?

- L3 prices actually increased more than L2 prices during session on average (4.5 vs. 3 francs).
- Thus the difference is due to a large difference in initial prices (13.5 vs. 8.75 on average).
  - Mean risk tolerance was higher in L2 than in L3.
  - Linear regression of mean B choices on initial price in linear sessions has coefficient 5.17 (p-value 0.0330) and R^2 of .8245.
  - Linear regression of mean B choices on initial price in all sessions has coefficient 4.19 (p-value 0.002) and R^2 of 0.7282
- Thus difference between L2 and L3 is in part attributable to the distribution of risk tolerance in these sessions.
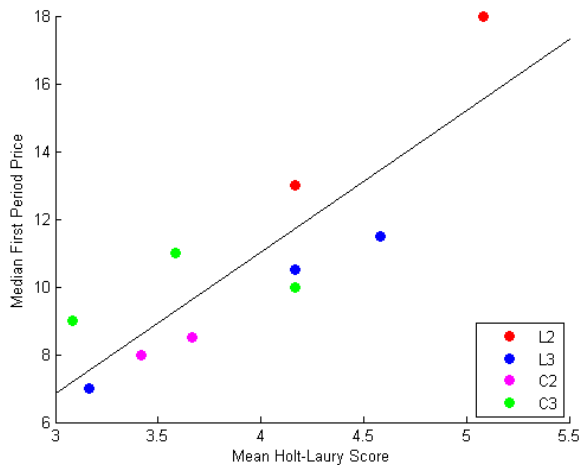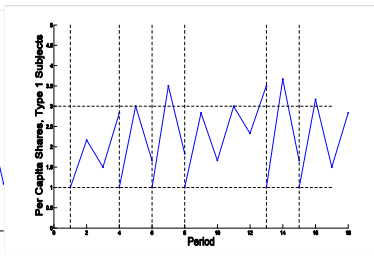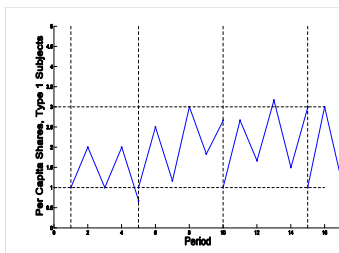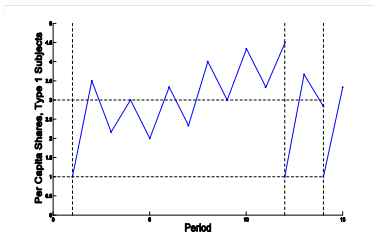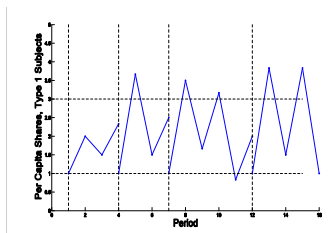
Finding 3: In the concave utility treatments there is strong evidence that subjects are using the asset to intertemporally smooth their consumption.
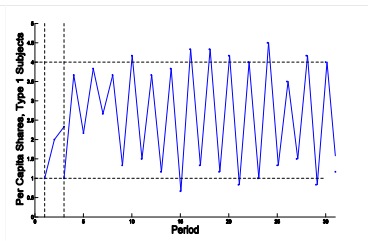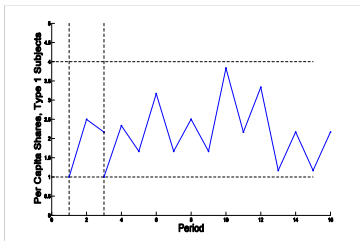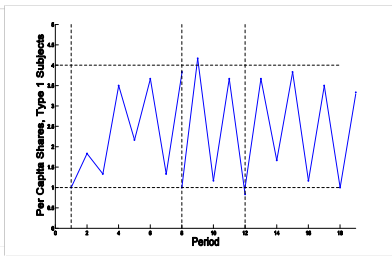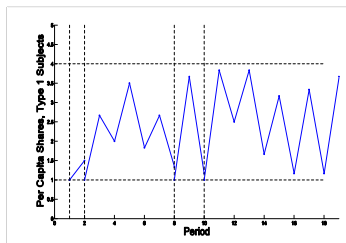
Consumption-smoothing behavior

Proportion of periods Type 1 players buy (sell) shares if the period is odd (even) and Type 2 players buy (sell) shares if the period is even (odd).
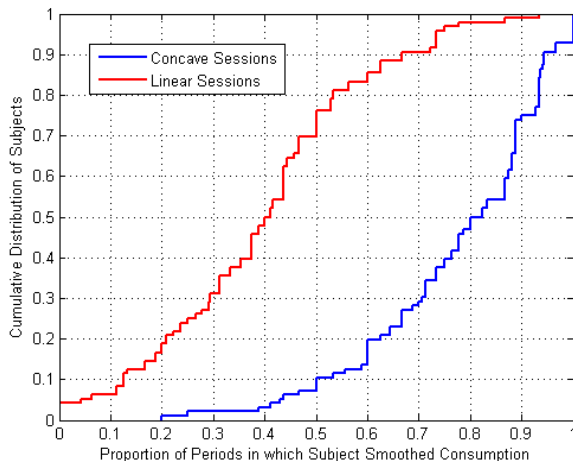
Finding 4: In the linear utility treatment, the asset is hoarded by just a few subjects.

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Mean Gini coefficient for shareholdings in final two periods of a session is 0.37 in all concave treatments (compared with 0.3 or lower in equilibrium). The Gini coefficient is 0.63 in all linear treatments (difference between concave and linear p-value 0.0008).

Distribution of Mean Shares During Final Two Periods
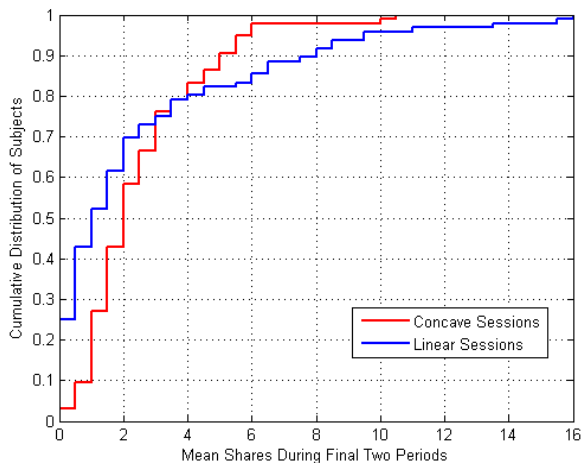
Finding 5: The more risk-tolerant subjects (according to the HL instrument) tend to accumulate more assets in linear sessions, but not in the concave sessions.

Risk Tolerance and Share Accumulation - Evidence

- Random effects regression of shares held during the final two periods on HL scores (#B choices).
  - Coefficient on #B choices is 0.46 in linear sessions (p-value 0.033)
    - Interpretation - Every two additional B choices leads to nearly one extra share held on average during the final two periods (per capita share endowment is only 2.5).
    - Results nearly identical for fixed effects regression.
  - Coefficient on B choices is -0.10 in the concave sessions (p-value 0.407)
- We obtain similar results from random effects regression of within-session *rank* of shareholders on HL scores. The highest and second highest ranked shareholders have average rank 8.3 (12=highest).
- Fixed effects specification produces similar results.

Results - Summary

- Relative to fundamental price / expected value, prices tend to be low when consumption-smoothing is induced via a concave utility function and high when with an induced linear utility function in otherwise identical economies.
- Most subjects smooth consumption in the concave sessions and rarely accumulate a large number of shares.
- The higher prices observed in the linear sessions are driven by a high share concentration among the most risk-tolerant subjects.

Some Further Extensions:

- Unpack the shock components of Hussam et al. 2008 to figure out what is necessary to rekindle a bubble among experienced subjects.

- Gender differences: SSW with all-female or all-male cohorts?

- Add an initial public offering (IPO) of shares (rather than giving these away to subjects) at an initial price that is below the first period fundamental value: do subjects buying shares in an IPO think harder about the asset's fundamental value over a T-period horizon?

- Fund management model (are $n > 1$ heads better than 1 / team behavior): One person forecasts price. Given this forecast, the other person makes an asset purchase decision (or some other consensus process).

- Test the capital-asset pricing model (CAPM) where assets are priced according to their sensitivity to non-diversifiable risk β, under the assumption of mean-variance preferences.