Asset Pricing Experiments: Bubbles, Crashes & Expectations

John Duffy

U. Pittsburgh

BLEESSM

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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:

\[ p_t = (1 + r)^{-1} E_t(d_{t+1} + p_{t+1}). \quad (1) \]
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, \( b_t \),

\[ p_t = f_t + b_t \]

(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).
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 $\bar{d}$.
- It is public knowledge that the fundamental value of an asset at the start of period $t$ is given by: $D^T_t = \bar{d}(T - t + 1) + D^T_{T+1}$. 


An Specific Parameterization (SSW Design #2)

Payoff = initial endowment of money + dividends on assets held + money received from sales of shares - the money spent on purchases of shares + buyout value.

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

<table>
<thead>
<tr>
<th>Players</th>
<th>Endowment (cash, quantity)</th>
<th>Number of players</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>($2.25; 3)</td>
<td>3</td>
</tr>
<tr>
<td>Class II</td>
<td>($5.85; 2)</td>
<td>3</td>
</tr>
<tr>
<td>Class III</td>
<td>($9.45; 1)</td>
<td>3</td>
</tr>
<tr>
<td>Dividends</td>
<td></td>
<td>(d \in {0, 0.04, 0.14, 0.20})(^a)</td>
</tr>
<tr>
<td>Initial value of a share</td>
<td>(\overline{D}_1 = 3.60) (b)</td>
<td></td>
</tr>
<tr>
<td>Buy-out value of a share</td>
<td>(\overline{D}^{T}_{T+1} = 1.80)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) 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.
Bubbles and Crash Phenomenon Illustrated
Bubbles Often Disappear With Experienced Subjects (Two 15 Round Sessions)
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 \( \beta \) 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 \(-0.03, -0.02, 0.005, 0.045\), so $\bar{d} = 0$. 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.
Lei et al.’s findings NoSpec/Spec illustrated
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

Market 1

Market 2

Market 3

Market 4
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.
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 $\bar{d}$ (alternatively, can be stochastic with known distribution).

No other task: given the 6 forecasts, actual prices are determined by a computer program using

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

where $\epsilon_t$ 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 $p_t = \bar{d} / r + \epsilon_t / r.$
Findings

- Monotonic and Oscillatory Convergence/Divergence are all observed.
- Often there is excess volatility relative to $\epsilon$ which is very small.
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.
The representative agent of type $i$ seeks to maximize:

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

subject to

$$c^i_t = y^i_t + d_t s^i_t - p_t (s^i_{t+1} - s^i_t),$$

$$y^i_t + d_t s^i_t - p_t (s^i_{t+1} - s^i_t) \geq 0,$$

$$s^i_t \geq 0.$$ 

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

$$p_t = \beta E_t \left[ \frac{u'(c^i_{t+1})}{u'(c^i_t)} (p_{t+1} + \bar{d}) \right].$$

Steady state equilibrium price: $p^* = \frac{\beta}{1-\beta} \bar{d}$. 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 \( \beta \) 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

<table>
<thead>
<tr>
<th>Type</th>
<th>No. Subjects</th>
<th>(s^i_1)</th>
<th>({y^i_t}) =</th>
<th>(u^i(c) =)</th>
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<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 c^{\phi^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 c^{\phi^2})</td>
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### 2 × 2 Treatment Design

<table>
<thead>
<tr>
<th></th>
<th>(\bar{d} = 2)</th>
<th>(\bar{d} = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concave (\phi^i &lt; 1) and (\alpha^i \phi^i &gt; 0)</td>
<td>C2 4 sessions</td>
<td>C3 4 sessions</td>
</tr>
<tr>
<td>Linear (\phi^i = 1)</td>
<td>L2 4 sessions</td>
<td>L3 4 sessions</td>
</tr>
</tbody>
</table>
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


- Ten choices between two lotteries, $A$ and $B$.
- $A$ paid $6$ or $4.80$, $B$ paid $11.55$ or $0.30$.
- In choice $n \in 1, 2, \ldots 10$, the probability of receiving the high payoff was $0.1 \times n$.
- 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).
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, $d=3$
<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>First Pd</th>
<th>Final Half</th>
<th>Final 5 Pds</th>
<th>Final Pd</th>
<th>Forecast</th>
<th>Change</th>
<th>Prob</th>
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<tr>
<td>C2</td>
<td>9.4</td>
<td>10.4</td>
<td>8.9</td>
<td>8.8</td>
<td>8.3</td>
<td>6.8</td>
<td>0.61</td>
<td>0.31</td>
</tr>
<tr>
<td>S1</td>
<td>7.1</td>
<td>15.0</td>
<td>5.5</td>
<td>5.2</td>
<td>6.0</td>
<td>9.7</td>
<td>0.16</td>
<td>0.27</td>
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<td>10.0</td>
<td>9.1</td>
<td>9.2</td>
<td>10</td>
<td>9.6</td>
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<td>7.5</td>
<td>0.61</td>
<td>0.31</td>
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<td>C3</td>
<td>11.6</td>
<td>9.3</td>
<td>11.4</td>
<td>11.2</td>
<td>10.8</td>
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<td>17.4</td>
<td>17.4</td>
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<td>0.38</td>
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<td>0.35</td>
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<tr>
<td>S13</td>
<td>14.8</td>
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<td>16.6</td>
<td>16.0</td>
<td>17.0</td>
<td>13.5</td>
<td>-1.29</td>
<td>0.78</td>
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</table>
Focus on final prices


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.
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).
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 0.8245.
  - 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.
Mean Session Risk Tolerance and Initial Prices

The graph illustrates the relationship between the Mean Session Risk Tolerance and the Initial Prices, with data points labeled L2, L3, C2, and C3. The x-axis represents the Mean Holt-Laury Score, while the y-axis shows the Median First Period Price. The data points are scattered along a linear trend, indicating a positive correlation between the two variables.
Finding 3: In the concave utility treatments there is strong evidence that subjects are using the asset to intertemporally smooth their consumption.
Concave $\bar{d} = 2$ sessions, per capita shares held by Type 1
Concave $\bar{d} = 3$ sessions per capita shares held by Type 1
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).
Assets are Hoarded in Linear Sessions

**Finding 4:** In the linear utility treatment, the asset is hoarded by just a few subjects.
Finding 4: In the linear utility treatment, the asset is hoarded by just a few subjects. 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

Cumulative Distribution of Subjects

Mean Shares During Final Two Periods

Concave Sessions
Linear Sessions
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.
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.
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 $\beta$, under the assumption of mean-variance preferences.