Speculative Growth, Overreaction, and the Welfare Cost of Technology-Driven Bubbles

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\textsuperscript{1}Any opinions expressed here do not necessarily reflect the views of the management of the Federal Reserve Bank of San Francisco or of the Board of Governors of the Federal Reserve System.
Overview

Excess volatility and bubbles can affect capital accumulation, growth, and welfare.

- The price-dividend ratio in standard RBC models is nearly constant. But U.S. price-dividend ratio is highly volatile.
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- Overreaction tends to be self-confirming, particularly when temporary innovations are perceived to be permanent.
- Speculation generates asset price bubbles that coincide with improved technology, investment booms, and faster growth.
- Speculation can improve welfare if CRRA \( \lesssim 1 - 1.5 \) and agents underinvest relative to socially-optimal level.
- When CRRA \( > 1.5 \), the welfare cost of speculation (and business cycles) can be large.
U.S. Price-Dividend Ratio is Volatile and Highly Persistent

S&P 500 Index: Price-Dividend Ratio, 1871-2008
Four Major Run-ups in U.S. Stock Prices

- **Early 1900s:** High-speed rail travel, transatlantic radio, long-line electrical transmission.

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- **Late 1990s**: Widespread availability of the internet, innovations in computers and information technology, emergence of web-based business model.
Comparing Two Bubble Episodes

Real S&P 500 Index During two 20-year Periods
(each series normalized to 100 at stock market peak)
Technology and the late-1990s Stock Market Bubble

“When we look back at the 1990s, from the perspective of say 2010...[w]e may conceivably conclude from that vantage point that, at the turn of the millennium, the American economy was experiencing a once-in-a-century acceleration of innovation, which propelled forward productivity, output, corporate profits, and stock prices at a pace not seen in generations, if ever.”
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“Alternatively, that 2010 retrospective might well conclude that a good deal of what we are currently experiencing was just one of the many euphoric speculative bubbles that have dotted human history. And, of course, we cannot rule out that we may look back and conclude that elements from both scenarios have been in play in recent years.”
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Stock Bubbles Distort Business Investment

Real Business Investment and Real S&P 500 Index
(each series normalized to 100 at the investment peak)
Stock Bubbles Influence Trend Growth
Rise and Fall of the “new economy.”

Potential GDP Growth and Detrended Stock Price Index

- CBO 4-Qtr Potential Output Growth (left scale)
- Real S&P 500, Deviation from HP Filter Trend (right scale)
Technology and the mid-2000s Housing Market Bubble

“[T]he financial services sector has been dramatically transformed by technology...With these advances in technology, lenders have taken advantage of credit-scoring models and other techniques for efficiently extending credit to a broader spectrum of consumers.”

Federal Reserve Chairman Alan Greenspan, April 8, 2005
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Housing Bubbles Distort Residential Investment

Real Residential Investment and Real House Price Index
(each series normalized to 100 at investment peak)
Related Literature (partial list)

- Rational Bubbles and Endogenous Growth (OLG Models)
  - Caballero, Farhi, and Hammour (2006)
  - Olivier (2000)
  - Grossman and Yanagawa (1993)
  - King and Ferguson (1993)
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- **Non-Fundamental Asset Price Movements and Investment**
  - Chirinko and Schaller (2001, 2007)
  - Gilchrist, Himmelberg, and Huberman (2005)
  - Johnson (2007)
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- Behavioral RBC Model (Optimism and Overconfidence)
  - Jaimovich and Rebelo (2007)
RBC Model with Endogenous Growth & Adjustment Costs
Along the lines of Barlevy (AER, 2004).

The representative agent (or capitalist-entrepreneur) maximizes

\[
E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{c_t^{1-\alpha} - 1}{1 - \alpha} \right], \quad \alpha = \text{CRRA} \quad \phi \equiv 1 - \alpha
\]

\[c_t + i_t = y_t\]

\[y_t = A \exp(z_t) \, k_t^\theta \, h_t^{1-\theta}\]

\[h_t = K_t, \quad \theta \in (0, 1]\]

\[k_{t+1} = B \, k_t^{1-\lambda} \, i_t^{\lambda}\]

\[\lambda \in (0, 1]\]

\[z_{t+1} = \rho z_t + \varepsilon_{t+1}\]

\[\varepsilon_{t+1} \sim N(0, \sigma^2_\varepsilon)\]
Adjustment Cost Formulation
Mapping to formulation of Jermann (JME, 1998) and Barlevy (AER, 2004).

\[
\frac{k_{t+1}}{k_t} = 1 - \delta + \psi_0 \left( \frac{i_t}{k_t} \right)^{\psi_1} \approx B \left( \frac{i_t}{k_t} \right)^{\lambda}
\]

\[
\lambda = \frac{\psi_0 \psi_1 (\frac{i}{k})^{\psi_1}}{1 - \delta + \psi_0 (\frac{i}{k})^{\psi_1}}
\]

\[
B = \frac{1 - \delta + \psi_0 (\frac{i}{k})^{\psi_1}}{(\frac{i}{k})^{\lambda}}
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(Taylor Coefficients)
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\[
\lambda = \frac{\psi_0 \psi_1 \left( i/k \right)^{\psi_1}}{1 - \delta + \psi_0 \left( i/k \right)^{\psi_1}}
\]

\[
B = \frac{1 - \delta + \psi_0 \left( i/k \right)^{\psi_1}}{\left( i/k \right)^{\lambda}} \quad \text{(Taylor Coefficients)}
\]

\[
i_t/\lambda = E_t \beta \left[ \frac{c_{t+1}}{c_t} \right]^{-\alpha} \left[ \theta y_{t+1} - i_{t+1} + \frac{i_{t+1}}{\lambda} \right] \quad \text{(FOC)}
\]

\[
\chi_t \equiv \frac{i_t/\lambda}{c_t} = \frac{p_t}{c_t} \quad \Rightarrow \quad \frac{p_t}{d_t} = \frac{\chi_t}{\theta - (1 - \theta) \lambda \chi_t}, \quad \text{(Stationary)}
\]
Model Solution

Investment-consumption ratio depends on technology shock (except for log utility).

\[
x_t^{1-\lambda \phi} \frac{\exp[(1-\lambda)\phi z_t]}{(1+\lambda x_t)^{(1-\lambda)\phi}} = E_t \frac{[\theta + x_{t+1}(1-\lambda+\lambda \theta)] \exp(\phi z_{t+1})}{(1+\lambda x_{t+1})^\phi} \ 
\]

\[
x_t \equiv \frac{i_t / \lambda}{c_t} = \frac{p_t}{c_t}, \quad \phi \equiv 1 - \text{CRRA}, \quad \tilde{\beta} \equiv \beta \left[(A\lambda)^\lambda B\right]^\phi
\]

Rational Law of Motion:

\[
t = e^t w \exp(m z_t), \quad z_t = \rho z_{t-1} + \varepsilon_t, \quad e^t w \exp\left[E\left(\log w_t\right)\right],
\]

Rational Forecast:

\[
E_t w_{t+1} = e^t w \exp(m \rho z_t + 1/2 m^2 \sigma^2 \varepsilon_t), \quad m = m(\text{CRRA}) = \text{rational technology response coefficient}.
\]
Model Solution

Investment-consumption ratio depends on technology shock (except for log utility).

\[
\frac{x_t^{1-\lambda} \exp[(1-\lambda) \phi z_t]}{(1+\lambda x_t)^{(1-\lambda)\phi}} = E_t \tilde{\beta} \left[ \frac{[\theta+x_{t+1}(1-\lambda+\lambda \theta)] \exp(\phi z_{t+1})}{(1+\lambda x_{t+1})^{\phi}} \right]^{\phi} \\
(FOC)
\]

\[
x_t \equiv \frac{i_t}{\lambda c_t} = \frac{p_t}{c_t}, \quad \phi \equiv 1 - CRRA, \quad \tilde{\beta} \equiv \beta \left[ (A\lambda)^\lambda B \right]^{\phi}
\]

Rational Law of Motion:
\[
w_t = \tilde{w} \exp(m z_t),
\]
\[
z_t = \rho z_{t-1} + \varepsilon_t,
\]
\[
\tilde{w} \equiv \exp[E(\log w_t)],
\]

Rational Forecast:
\[
E_t w_{t+1} = \tilde{w} \exp[m \rho z_t + \frac{1}{2} m^2 \sigma^2_{\varepsilon}],
\]

\[
m = m(CRRA) = \text{rational technology response coefficient.}
\]
Rational Behavior vs. Self-Confirming Overreaction
Temporary technology innovations are perceived to be permanent.

Rational Law of Motion:
\[ w_t = \tilde{w} \exp(m z_t), \]
\[ z_t = \rho z_{t-1} + \epsilon_t, \]

Perceived Law of Motion (PLM):
\[ w_{s,t} = \tilde{w}_s \exp(m_s z_t), \]
\[ z_t = z_{t-1} + u_t, \]
Rational Behavior vs. Self-Confirming Overreaction

Temporary technology innovations are perceived to be permanent.

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\begin{align*}
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\end{align*}
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\[
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& \quad z_t = z_{t-1} + u_t,
\end{align*}
\]

\[
\begin{align*}
\text{Speculative Forecast:} & \quad \hat{E}_t w_{s,t+1} = \tilde{w}_s \exp [m_s z_t + \frac{1}{2} m_s^2 \sigma_u^2],
\end{align*}
\]

\[
\begin{align*}
\text{Actual Law of Motion (ALM):} & \quad w_{s,t} = \tilde{w}_s \exp [f(m_s) z_t], \quad \text{where} \quad f'(m_s) \approx 1.
\end{align*}
\]

\[m_s > m \text{ is calibrated to match std. dev. of } \frac{p_t}{d_t} \text{ in U.S. data.}\]
## Calibrating the Speculation Model to Fit U.S. Data

Rational model uses same parameter values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description/Empirical Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>0.4</td>
<td>Capital share of income.</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>1.5</td>
<td>Degree of risk aversion.</td>
</tr>
<tr>
<td>$A$</td>
<td>0.333</td>
<td>Mean $k_t/y_t = 3$.</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.070</td>
<td>Mean $i_t/y_t = 0.25$.</td>
</tr>
<tr>
<td>$B$</td>
<td>1.216</td>
<td>Mean consumption growth $= 1.98 %$.</td>
</tr>
<tr>
<td>$\sigma_\varepsilon$</td>
<td>0.059</td>
<td>Std. dev. consumption growth $= 3.99 %$.</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.9</td>
<td>Annual technology shock persistence.</td>
</tr>
<tr>
<td>$\sigma_u$</td>
<td>0.060</td>
<td>Perceived innovation variance.</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.967</td>
<td>Mean $p_t/d_t = 26.6$</td>
</tr>
<tr>
<td>$m_s$</td>
<td>1.165</td>
<td>Std. dev. $p_t/d_t = 13.8$</td>
</tr>
<tr>
<td>$m$</td>
<td>$-0.427$</td>
<td>Rational model value.</td>
</tr>
</tbody>
</table>
Overreaction Behavior Tends to be Self-Confirming
Observed forecast errors are close to white noise.
Real-Time Learning Paths
Estimated technology response coefficient is path-dependent.

Real-time Learning Paths in Nonlinear Model
(with agent misperception of technology process)

Real-Time Learning Paths in Nonlinear Model
(with agent learning about technology process)
Model Simulations
Speculative bubbles coincide with economic booms and excess capital formation.
Business Cycle Behavior
Speculation magnifies investment volatility but reduces consumption volatility.
## Volatility of Real Growth Rates: Model versus Data

Speculation model outperforms rational model in matching data.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dates</th>
<th>U.S. Economy</th>
<th>Rational Model</th>
<th>Speculation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta \log (y_t) )</td>
<td>1871-2008</td>
<td>5.28</td>
<td>5.93</td>
<td>5.94</td>
</tr>
<tr>
<td>( \Delta \log (c_t) )</td>
<td>1890-2008</td>
<td>3.99</td>
<td>5.82</td>
<td>3.98</td>
</tr>
<tr>
<td>( \Delta \log (i_t) )</td>
<td>1930-2008</td>
<td>16.2</td>
<td>6.24</td>
<td>12.2</td>
</tr>
<tr>
<td>( \Delta \log (d_t) )</td>
<td>1872-2008</td>
<td>12.2</td>
<td>5.42</td>
<td>7.80</td>
</tr>
<tr>
<td>( \Delta \log (p_t) )</td>
<td>1872-2008</td>
<td>17.9</td>
<td>6.24</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Note: In percent, from 15,000 period simulation with \( \theta = 0.4 \), CRRA = 1.5.
**Asset Pricing Moments: Model versus Data**

Speculation model outperforms rational model in matching data.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>U.S. Data</th>
<th>Rational Model</th>
<th>Speculation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean $p_t/d_t$</td>
<td>25.6</td>
<td>22.8</td>
<td>26.6</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>13.8</td>
<td>0.42</td>
<td>13.7</td>
</tr>
<tr>
<td>Skew.</td>
<td>2.20</td>
<td>0.04</td>
<td>4.12</td>
</tr>
<tr>
<td>Kurt.</td>
<td>8.21</td>
<td>2.94</td>
<td>42.1</td>
</tr>
<tr>
<td>Corr. Lag 1</td>
<td>0.93</td>
<td>0.90</td>
<td>0.84</td>
</tr>
<tr>
<td>Mean $R_t$</td>
<td>7.84 %</td>
<td>6.64 %</td>
<td>7.26 %</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>17.8 %</td>
<td>6.63%</td>
<td>12.6 %</td>
</tr>
<tr>
<td>Corr. Lag 1</td>
<td>0.04</td>
<td>−0.04</td>
<td>−0.06</td>
</tr>
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Computed from 15,000 period simulation with $\theta = 0.4$, CRRA = 1.5.
Fluctuations (due to speculation or business cycles) can affect the mean and volatility of consumption growth.
Intuition for Welfare Results

- Fluctuations (due to speculation or business cycles) can affect the mean and volatility of consumption growth.

- Decreased consumption growth implies less resources devoted to investment, and hence a higher initial consumption $E(c_0)$.
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- As CRRA increases, consumption growth volatility becomes more costly.

- Which of these effects dominates depends on parameter values.
Intuition for Welfare Results (continued)

- Speculation increases mean growth at low levels of actual risk aversion, but the reverse holds true for higher risk aversion.

### Mean and Volatility of Consumption Growth (with \( \theta = 0.4 \))

<table>
<thead>
<tr>
<th>( \alpha )</th>
<th>Statistic</th>
<th>Deterministic Model</th>
<th>Rational Model</th>
<th>Speculation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>Mean</td>
<td>1.62</td>
<td>1.61</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>0</td>
<td>6.09</td>
<td>3.97</td>
</tr>
<tr>
<td>1.5</td>
<td>Mean</td>
<td>1.96</td>
<td>1.94</td>
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Note: In percent. Statistics are averages from a 15,000 period simulation.
Welfare Costs (in percent of per-period consumption)
1 percent of consumption = $100 billion in 2007 dollars.

<table>
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<tr>
<th>( \alpha )</th>
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</tr>
<tr>
<td>1.0</td>
<td>-3.21</td>
<td>-2.56</td>
<td>4.72</td>
</tr>
<tr>
<td>1.5</td>
<td>0.74</td>
<td>-1.11</td>
<td>3.55</td>
</tr>
<tr>
<td>2.0</td>
<td>4.76</td>
<td>0.48</td>
<td>2.67</td>
</tr>
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<td>2.28</td>
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Welfare Costs (in percent of per-period consumption)

1 percent of consumption = $100 billion in 2007 dollars.

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<thead>
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Welfare Costs
Costs increase rapidly with risk aversion when agents underinvest.
Conclusion

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For higher degrees of risk aversion, the welfare costs of speculation and business cycles can be large.
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Fed Chairman Ben Bernanke, October 15, 2008