FINANCIAL CRISES
SYSTEMIC RISKS

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MOTIVATIONS

• Do excesses exist? Financial bubbles?
• Why are they so difficult to identify? (academic view vs. practitioners vs Fed)
• Real-estate bubble and MBS bubble
• Why are they dangerous? Systemic risks
• What can be done? Better metrics vs. moral hazard and herding
Academic Literature:
No consensus on what is a bubble...

Ex:

Can asset price bubbles be detected? This survey of econometric tests of asset price bubbles shows that, despite recent advances, econometric detection of asset price bubbles cannot be achieved with a satisfactory degree of certainty. For each paper that finds evidence of bubbles, there is another one that fits the data equally well without allowing for a bubble. We are still unable to distinguish bubbles from time-varying or regime-switching fundamentals, while many small sample econometrics problems of bubble tests remain unresolved.

*Journal of Economic Surveys (2008)*
“We, at the Federal Reserve...recognized that, despite our suspicions, it was very difficult to definitively identify a bubble until after the fact, that is, when its bursting confirmed its existence... Moreover, it was far from obvious that bubbles, even if identified early, could be preempted short of the Central Bank inducing a substantial contraction in economic activity, the very outcome we would be seeking to avoid.”
An Overview of Speculative Bubbles and Market Crashes

Real Stock Price (S&P500)

Super-exponential growth of the major indices over long time periods.
Proximate explanations after the fact!

Computer trading
Derivatives
Illiquidity
Trade and budget deficits
Over-valuation
The auction system
Off-market and off-hours trading
Floor brokers
Forward market effect
Different investor styles
Stock market crashes are often unforeseen for most people, especially economists. “In a few months, I expect to see the stock market much higher than today.” Irving Fisher, famous economist and professor of economics at Yale University, 14 days before Wall Street crashed on Black Tuesday, October 29, 1929.

“A severe depression such as 1920–21 is outside the range of probability. We are not facing a protracted liquidation.” This was the analysis offered days after the crash by the Harvard Economic Society to its subscribers… It closed its doors in 1932.

The DJIA prior to the October 1929 crash on Wall Street.

“New Economy”: utilities
THE NASDAQ CRASH OF APRIL 2000

“New Economy”: ICT

[Graph showing the log of Nasdaq Composite over time with best fit and third best fit lines.]
THE NASDAQ CRASH OF APRIL 2000

• 1995-2000: growing divergence between New Economy and Old Economy stocks, between technology and almost everything else.

• Over 1998 and 1999, stocks in the Standard & Poor’s technology sector rose nearly fourfold, while the S&P 500 index gained just 50%. And without technology, the benchmark would be flat.

• In January 2000 alone, 30% of net inflows into mutual funds went to science and technology funds, versus just 8.7% into S&P 500 index funds.

• The average price-over-earnings ratio (P/E) for Nasdaq companies was above 200.

• New Economy was also hot in the minds and mouths of investors in the 1920s and in the early 1960s. In 1929, it was utilities; in 1962, it was the electronic sector.
EXPECTATIONS of strong future growth

• better business models (small required capital, reduced delay in payments…)

• the network effect (positive returns and positive feedbacks)

• first-to-scale advantages

• real options (value of fast adaptation to grasp new opportunities)

Probably true... but problem of timing...
Fig. 2. Fit of the time evolution of the foreign net capital inflow $I(t)$ in the USA from 1975 till the first quarter of 2001 when it reached its maximum, by a second-order Weierstrass-type function given by expression (1). The predicted critical time is $t_c = 2001/03/12$, the power-law exponent is $m = 0.01$, and the angular log-frequency is $\omega = 4.9$. The fitted linear parameters are $A = 7355$, $B = -6719$, $C_1 = 21.5$ and $C_2 = 16.2$. The r.m.s. of the residuals of the fit is 22.810.
Various Bubbles and Crashes

Each bubble has been rescaled vertically and translated to end at the time of the crash.
Many other bubbles and crashes

- Hong-Kong crashes: 1987, 1994, 1997 and many others
- October 1997 mini-crash
- August 1998
- Slow crash of spring 1962
- Latin-american crashes
- Asian market crashes
- Russian crashes
- Individual companies
Textbook example of a series of superexponential acceleration followed by crashes

Arrows show peaks followed by corrections of more than 15% in less than three weeks
The market is never following the average growth; it is either super-exponentially accelerating or crashing.

Red line is 13.8% per year: but

Patterns of price trajectory during 0.5-1 year before each peak: Log-periodic power law.
Universal Bubble and Crash Scenario

1. The bubble starts smoothly with some increasing production and sales (or demand for some commodity) in an otherwise relatively optimistic market.

2. The attraction to investments with good potential gains then leads to increasing investments, possibly with leverage coming from novel sources, often from international investors. This leads to price appreciation.

3. This in turn attracts less sophisticated investors and, in addition, leveraging is further developed with small downpayment (small margins), which leads to the demand for stock rising faster than the rate at which real money is put in the market.

4. At this stage, the behavior of the market becomes weakly coupled or practically uncoupled from real wealth (industrial and service) production.

5. As the price skyrockets, the number of new investors entering the speculative market decreases and the market enters a phase of larger nervousness, until a point when the instability is revealed and the market collapses.
The upswing usually starts with an opportunity - new markets, new technologies or some dramatic political change - and investors looking for good returns.

· It proceeds through the euphoria of rising prices, particularly of assets, while an expansion of credit inflates the bubble.

· In the manic phase, investors scramble to get out of money and into illiquid things such as stocks, commodities, real estate or tulip bulbs: 'a larger and larger group of people seeks to become rich without a real understanding of the processes involved'.

· Ultimately, the markets stop rising and people who have borrowed heavily find themselves overstretched. This is 'distress', which generates unexpected failures, followed by 'revulsion' or 'discredit'.

· The final phase is a self-feeding panic, where the bubble bursts. People of wealth and credit scramble to unload whatever they have bought at greater and greater losses, and cash becomes king.

Charles Kindleberger, Manias, Panics and Crashes (1978)
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• Real-estate bubble and MBS bubble
• Why are they dangerous? Systemic risks
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What is the cause of the crash?

✓ Proximate causes: many possibilities

✓ Fundamental cause: maturation towards an instability

An instability is characterized by

• large or diverging susceptibility to external perturbations or influences
• exponential growth of random perturbations leading to a change of regime, or selection of a new attractor of the dynamics.
For humans data at the time could not discriminate between:
1. exponential growth of Malthus
2. logistic growth of Verhulst

But data fit on animal population: sheep in Tasmania

- exponential in the first 20 years after their introduction and completely saturated after about half a century. ==> Verhulst
Positive feedbacks and finite-time singularity
Super-exponential growth

Conjecture: Many systems exhibit transient FTS as “ghost-like” solutions that the system follows for a while before being attenuated.
Analogous to exponential sensitivity to initial condition with reinjection → chaos but here FTS blow-up.

\[
\frac{dp}{dt} = rp(t)[K - p(t)],
\]

\[
\frac{dp}{dt} = r[p(t)]^{1+\delta},
\]

with \( K \propto p^\delta \)

\[ p(t) \propto (t_c - t)^z, \text{ with } z = -\frac{1}{\delta} \text{ and } t \text{ close to } t_c. \]

Multi-dimensional generalization: multi-variate positive feedbacks
Super-exponential growth

\[ \frac{dp}{dt} = rp(t)[K - p(t)]. \]
Mechanisms for positive feedbacks in the stock market

- **Technical and rational mechanisms**
  1. Option hedging
  2. Insurance portfolio strategies
  3. Trend following investment strategies
  4. Asymmetric information on hedging strategies

- **Behavioral mechanisms:**
  1. Breakdown of “psychological Galilean invariance”
  2. Imitation (many persons)
    a) It is rational to imitate
    b) It is the highest cognitive task to imitate
    c) We mostly learn by imitation
    d) The concept of “CONVENTION” (Orléan)
Super-exponential growth of the major indices over long time periods

Super-exponential growth
Figure 1: Monthly Capital Appreciation Index 1/1815-12/1999

Super-exponential growth

Price-weighted NYSE Index (1/1815-12/1925) with Ibbotson and Sinquefield Index (1/1926-12/1999)

A NEW HISTORICAL DATABASE FOR THE NYSE 1815 TO 1925: PERFORMANCE AND PREDICTABILITY

W.N. Goetzmann, R.G. Ibbotson and L. Peng
Yale School of Management, July 14, 2000
Finite-time Singularity

- Planet formation in solar system by run-away accretion of planetesimals
- PDE’s: Euler equations of inviscid fluids and relationship with turbulence
- PDE’s of General Relativity coupled to a mass field leading to the formation of black holes
- Zakharov-equation of beam-driven Langmuir turbulence in plasma
- rupture and material failure
- Earthquakes (ex: slip-velocity Ruina-Dieterich friction law and accelerating creep)
- Models of micro-organisms chemotaxis, aggregating to form fruiting bodies
- Surface instability spikes (Mullins-Sekerka), jets from a singular surface, fluid drop snap-off
- Euler’s disk (rotating coin)
- Stock market crashes...
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Short random runs of news can be amplified into bubbles by herding optimizing traders

http://arXiv.org/abs/0806.2989

Opinion formation

\[ \text{opinion}_i(t) = c_{1i} \cdot \sum_{j=1}^{J} k_{ij} E_i[s_j(t)] + c_{2i} \cdot u(t) \cdot \text{news}(t) + c_{3i} \cdot \varepsilon_i(t) \]

- **Imitation term**
- **News term**
- **Idiosyncratic term**

Trading decision

- if \( \text{opinion}_i(t) > |\text{opinion-th}_i| \) : \( s_i(t) = +1 \)
  \[ a_i(t) = g \cdot \frac{\text{cash}_i(t)}{\text{price}(t-1)} \]
- if \( \text{opinion}_i(t) < -|\text{opinion-th}_i| \) : \( s_i(t) = -1 \)
  \[ a_i(t) = g \cdot \text{stocks}_i(t) \]

Learning and adaptation

\[ k_{ij}(t) = \alpha \cdot k_{ij}(t-1) + r(t-1) \cdot E_i[s_j(t-2)] \cdot \frac{1-\alpha}{\sigma_{r}} \]

\[ u(t) = \alpha \cdot u(t-1) + r(t-1) \cdot \text{news}(t-2) \cdot \frac{1-\alpha}{\sigma_{r}} \]
Price clearing condition

\[ r(t) = \frac{1}{\lambda \cdot N} \sum_{i=1}^{N} s_i(t) \cdot a_i(t) \]

\[ \log[\text{price}(t)] = \log[\text{price}(t - 1)] + r(t), \]

Wealth evolution

\[ \text{cash}_i(t) = \text{cash}_i(t - 1) - a_i(t) \cdot \text{price}(t) \]

\[ \text{stock}_i(t) = \text{stock}_i(t - 1) + a_i(t). \]
$C_1 = C_2 = C_3 = 1.0$
ENDO-EXO view of bubbles and crashes; Transient runs of news are sufficient to trigger large crashes in a system of over-learning and over-controlling agents.
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Real-estate bubbles

Percentage change in real housing prices 2002–2006

Sources: Shiller; BIS.
Real-estate in the UK

Fig. 1. (Color online) Plot of the UK Halifax house price indices from 1993 to April 2005 (the latest available quote at the time of writing). The two groups of vertical lines correspond to the two predicted turning points reported in Tables 2 and 3 of [1]: end of 2003 and mid-2004. The former (resp. later) was based on the use of formula (2) (resp. (3)). These predictions were performed in February 2003.

Fig. 5. (Color online) Quarterly average HPI in the 21 states and in the District of Columbia (DC) exhibiting a clear upward faster-than-exponential growth. For better representation, we have normalized the house price indices for the second quarter of 1992 to 100 in all 22 cases. The corresponding states are given in the legend.

Our study in 2005 identifies the bubble states.

Fall 2007
Over the past decade and a half, (B - F) has been closely correlated with realized capital gains on the sale of homes.
This graph shows the year-over-year price changes for the Case-Shiller composite 10 and 20 indices (through February), and the Case-Shiller and OFHEO National price indices (through Q4 2007).
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Securitisation model

- Borrower
- Lender
- Servicer
- Investment Bank
- Investor

Mortgage Broker

Credit Rating Agencies

Loan Contract

Loan

Monthly Payments

Cash

Securities

Monthly Payments

Cash
Securitization of credit risks

Securitization of credit risks leads to smaller risks

But more inter-connected ⇒ global risk?

CDS and CDO: form of insurance contracts linked to underlying debt that protects the buyer in case of default.

The market has almost doubled in size every year for the past five years, reaching $20 trillion in notional amounts outstanding last June 2007, according to the Bank for International Settlements.

Bundling of indexes of CDSs together and slicing them into trenches, based on riskiness and return. The most toxic trench at the bottom exposes the holder to the first 3% of losses but also gives him a large portion of the returns. At the top, the risks and returns are much smaller-unless there is a systemic failure.
Subprime financial crisis

US housing boom

Expectation on rising price

Individual borrower

Commercial bank
Wall Street lender

Mortgage lender

Structured investment Vehicles (SIVs)

Hedge funds, pension funds and other financial institutions

Mortgage-backed securities, CDOs

Financing counterpart
Separation of financial and credit risks

Securitization leads to larger inter-connectivity

pdf

risks

pdf

risks
SYNCHRONISATION AND COLLECTIVE EFFECTS IN EXTENDED STOCHASTIC SYSTEMS

Fireflies

FIG. 1. Evolution of the cumulative earthquake slip, represented along the vertical axis in the white to black color code shown above the picture, at two different times: (a) early time and (b) long time, in a system of size \( L = \beta = 1.9 \) and \( \Delta t = 0.1 \).

Miltenberger et al. (1993)
"Phase diagram" for the model in the space (heterogeneity, stress drop). Crosses (+) correspond to systems which exhibit a periodic time evolution. Stars * corresponds to systems that are self-organized critical, with a Gutenberg-Richter earthquake size distribution and fault localization whose geometry is well-described by the geometry of random directed polymers.
Gutenberg-Richter distribution of sizes

Omori law: Direct and Inverse

The longer it has been since the last event, the longer it will be since the next one!
19 rats treated intravenously (2) with the convulsant 3-mercapto-proprionic acid (3-MPA)
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Comparison of the Federal funds rate, the S&P 500 Index $x(t)$, and the NASDAQ composite $z(t)$, from 1999 to mid-2003. To allow a illustrative visual comparison, the indices have been translated and scaled as follows: $x \rightarrow 5x - 34$ and $z \rightarrow 10z - 67$. 
Cross-correlation coefficient $C(n)$ between the increments of the logarithm of the S&P 500 Index and the increments of the Federal funds rate as a function of time lag $n$ in days. The three curves correspond to three different time steps used to calculate the increments: weekly, monthly and quarterly. A positive lag $n$ corresponds to having the Federal funds rate posterior to the stock market.

ARE CRASHES EXCEPTIONAL?

Traditional emphasis on Daily returns do not reveal any anomalous events
Better risk measure: drawdowns
A. Johansen and D. Sornette, Stock market crashes are outliers, European Physical Journal B 1, 141-143 (1998)

Outliers, Kings
(require special mechanism and may be more predictable)

Dow Jones Industrial Average

<table>
<thead>
<tr>
<th>Cut-off $u$</th>
<th>Quantile</th>
<th>$z$</th>
<th>$\ln(L_0)$</th>
<th>$\ln(L_1)$</th>
<th>$T$</th>
<th>Proba</th>
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<tr>
<td>3%</td>
<td>87%</td>
<td>0.916</td>
<td>4890.36</td>
<td>4891.16</td>
<td>1.6</td>
<td>20.5%</td>
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<td>6%</td>
<td>97%</td>
<td>0.875</td>
<td>4944.36</td>
<td>4947.06</td>
<td>5.4</td>
<td>2.0%</td>
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<td>9%</td>
<td>99.0%</td>
<td>0.869</td>
<td>4900.75</td>
<td>4903.66</td>
<td>5.8</td>
<td>1.6%</td>
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<td>12%</td>
<td>99.7%</td>
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<td>4872.47</td>
<td>4877.46</td>
<td>10.0</td>
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<tr>
<td>15%</td>
<td>99.7%</td>
<td>0.843</td>
<td>4854.97</td>
<td>4860.77</td>
<td>11.6</td>
<td>0.07%</td>
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<td>18%</td>
<td>99.9%</td>
<td>0.836</td>
<td>4845.16</td>
<td>4851.94</td>
<td>13.6</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

Fig. 7. French agglomerations: stretched exponential and “King effect”.
Endogenous vs exogenous crashes

1. Systematic qualification of outliers/kings in pdfs of drawdowns

2. Existence or absence of a “critical” behavior by LPPL patterns found systematically in the price trajectories preceding this outliers

Results: In worldwide stock markets + currencies + bonds

• 21 endogenous crashes
• 10 exogenous crashes

A. Johansen and D. Sornette,
Endogenous versus Exogenous Crashes in Financial Markets,
in press in "Contemporary Issues in International Finance"
(http://arXiv.org/abs/cond-mat/0210509)
Continuous line: first-order LPPL
Dashed line: second-order LPPL
Out-of-sample test over 20 years of the Heng Seng

Alarms were produced in the following nine time intervals containing the date of the last point used in the fit:

(a) 1981.60 to 1981.68. This was followed by a \( \approx 30\% \) decline.
(b) 1984.36 to 1984.41. This was followed by a \( \approx 30\% \) decline.
(c) 1985.20 to 1985.30; false alarm.
(d) 1987.66 to 1987.82. This was followed by a \( \approx 50\% \) decline.
(e) 1989.32 to 1989.38. This was followed by a \( \approx 35\% \) decline.
(f) 1991.54 to 1991.69. This was followed by a \( \approx 7\% \) single day decline; considered a false alarm, nevertheless.
(g) 1992.37 to 1992.58. This was followed by a \( \approx 15\% \) decline. This is a marginal case.
(h) 1993.79 to 1993.90. This was followed by a \( \approx 20\% \) decline. This can also be considered as a marginal case, if we want to be conservative.
(i) 1997.58 to 1997.74. This was followed by \( \approx 35\% \) decline.
Figure 42: Thai stock market bubble ending with the crash of Jan. 94. See table 5 for the parameter values of the fit with equation (1).

\[ I(t) = A + B (t_c - t)^z + C(t_c - t)^z \cos(\omega \log(t_c - t) - \phi) \]

Parameters of the log-periodic fits; \( z \) = critical exponent; \( \omega \) = log-periodic frequency

<table>
<thead>
<tr>
<th>Stock market</th>
<th>( A )</th>
<th>( B )</th>
<th>( C )</th>
<th>( z )</th>
<th>( t_c )</th>
<th>( \omega )</th>
<th>( \phi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong-Kong I</td>
<td>5523; 4533</td>
<td>-3247; -2304</td>
<td>171; -174</td>
<td>0.29; 0.39</td>
<td>87.84; 87.78</td>
<td>5.6; 5.2</td>
<td>-1.6; 1.1</td>
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<tr>
<td>Hong-Kong II</td>
<td>21121</td>
<td>-15113</td>
<td>-429</td>
<td>0.12</td>
<td>94.02</td>
<td>6.3</td>
<td>-0.6</td>
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<tr>
<td>Hong-Kong III</td>
<td>20077</td>
<td>-8241</td>
<td>-397</td>
<td>0.34</td>
<td>97.74</td>
<td>7.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Indonesia I</td>
<td>6.76</td>
<td>-1.11</td>
<td>0.029</td>
<td>0.12</td>
<td>94.09</td>
<td>15.6</td>
<td>-1.3</td>
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<tr>
<td>Indonesia II</td>
<td>7.38</td>
<td>-0.92</td>
<td>-0.06</td>
<td>0.23</td>
<td>98.05</td>
<td>10.08</td>
<td>5.8</td>
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<tr>
<td>Korea I</td>
<td>6.97</td>
<td>-0.28</td>
<td>-0.05</td>
<td>1.05</td>
<td>94.87</td>
<td>8.15</td>
<td>1.1</td>
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<tr>
<td>Malaysia I</td>
<td>7.61</td>
<td>-1.16</td>
<td>0.013</td>
<td>0.24</td>
<td>94.02</td>
<td>10.9</td>
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<tr>
<td>Philippines I</td>
<td>9.00</td>
<td>-1.74</td>
<td>-0.078</td>
<td>0.16</td>
<td>94.02</td>
<td>8.2</td>
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<tr>
<td>Thailand I</td>
<td>7.81</td>
<td>-1.41</td>
<td>-0.086</td>
<td>0.48</td>
<td>94.07</td>
<td>6.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>
\[ I(t) = A + B (t_c - t) \gamma + C (t_c - t) \gamma \cos (\omega \log (t_c - t) - \phi) \]

Figure 5: Empirical distribution of the log-periodic angular frequency \( \omega \) in eq. (1) for over thirty case studies. The fit with a Gaussian distribution gives \( \omega \approx 6.36 \pm 1.55 \). The smaller peak centered on 11–12 suggests the existence of a second discernable harmonics at \( 2\omega \approx 12 \).

Demonstration of universal values of \( \gamma \) and omega across many different bubbles at different epochs and different markets


Figure 6: Empirical distribution of the exponent \( \gamma \) of the power law in eq. (1) for over thirty case studies. The fit with a Gaussian distribution gives \( \beta \approx 0.33 \pm 0.18 \).
What are bubbles? 
How do detect them? 
How to predict them?

Our proposition to the Academic Literature: 
“Super exponential price acceleration” and “king” effect

Our proposition to the Fed: 
Complex system approach with emphasis on 
(i) positive and negative feedback interplay (“procyclical”) 
(ii) collective behavior and organization lead to “EMERGENCE” of CRITICAL POINTS 
(iii) novel metrics to monitor the development of bubbles 
(iv) moral hazard
Hang Seng China Entreprises Index (HSCEI)
Typical result of the calibration of the simple LPPL model to the oil price in US $ in shrinking windows with starting dates $t_{\text{start}}$ moving up towards the common last date $t_{\text{last}} = \text{May 27, 2008}$. 

Speculation vs supply-demand
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Predictions and Preparation: complexity theory applied to such collective processes provides clues for precursors and suggests steps for precaution and preparation.
Why bubbles are not arbitrated away?

1. limits to arbitrage caused by noise traders (DeLong et al., 1990)
2. limits to arbitrage caused by synchronization risk (Abreu and Brunnermeier, 2002 and 2003)
3. short-sale constraints (many papers)
4. lack of close substitutes for hedging (many papers)
5. heterogeneous beliefs (many papers)
6. lack of higher-order mutual knowledge (Allen, Morris and Postlewaite, 1993)
7. delegated investments (Allen and Gorton, 1993)
8. psychological biases (observed in many experiments)
9. positive feedback bubbles