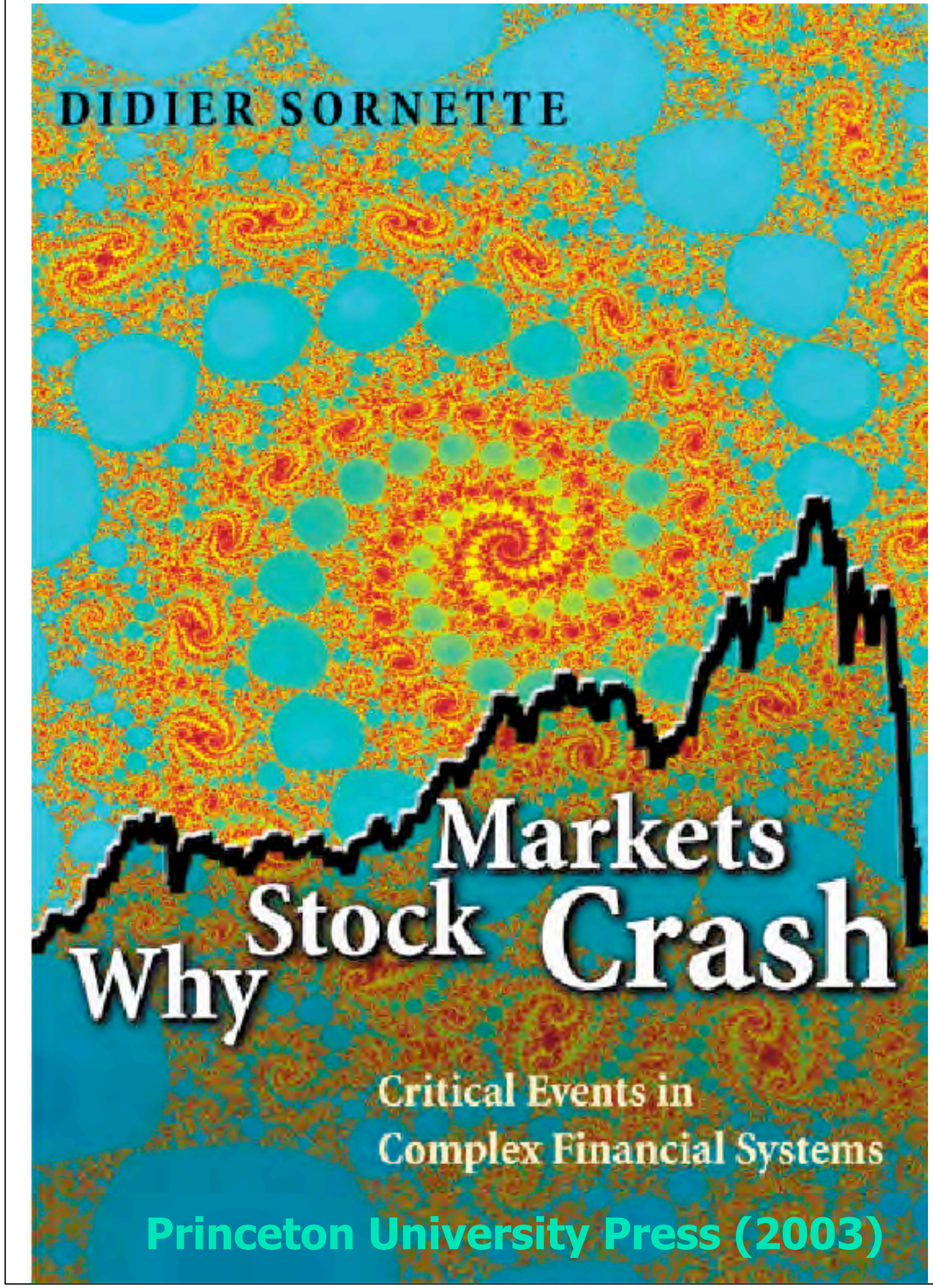
Out-of-equilibrium nonlinear financial economics



Princeton University Press (2003)

D. Sornette

Professor of Entrepreneurial Risks at ETH Zurich

Professor of Finance at the Swiss Finance Institute

Director of the Financial Crisis Observatory

Founding member of the Risk Center at ETH Zurich (June 2011) (www.riskcenter.ethz.ch)

Professor of Geophysics associated with the Department of Earth Sciences (D-ERWD), ETH Zurich

Professor of Physics associated with the Department of Physics (D-PHYS), ETH Zurich

Out-of-equilibrium nonlinear financial economics

- Financial bubble experiments at ETH Zurich
- Reverse engineering of financial markets with agent-based models
- Illusion of control
- Multifractal endogenous econometric models for augmented variance estimators and forecasting
- Time-dependent lead-lag in econometrics
- Quantum decision theory

Crises are not black swans but “Dragon-kings”

Black Swan (*Cygnus atratus*)

Black Swan story

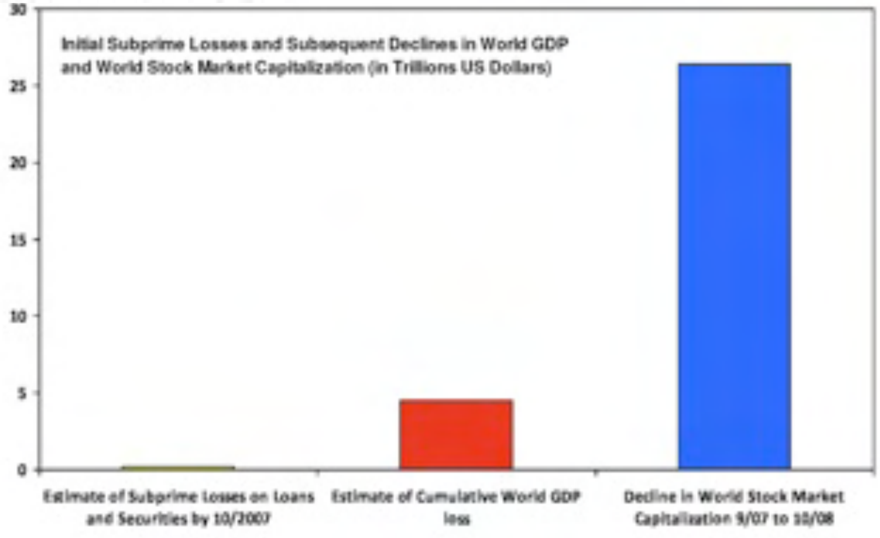
- Unknown unknowable event
  - ★ cannot be diagnosed in advance, cannot be quantified, no predictability
- No responsability ("wrath of God")
- One unique strategy: long put options and insurance


Chart 1: HOME PRICES — STILL DEFLATING AFTER ALL THESE YEARS

United States

S&P/Case-Shiller Home Price Index: Composite 20
(Jan 2000 = 100, seasonally adjusted)

Source: Haver Analytics, Gluskin Sheff

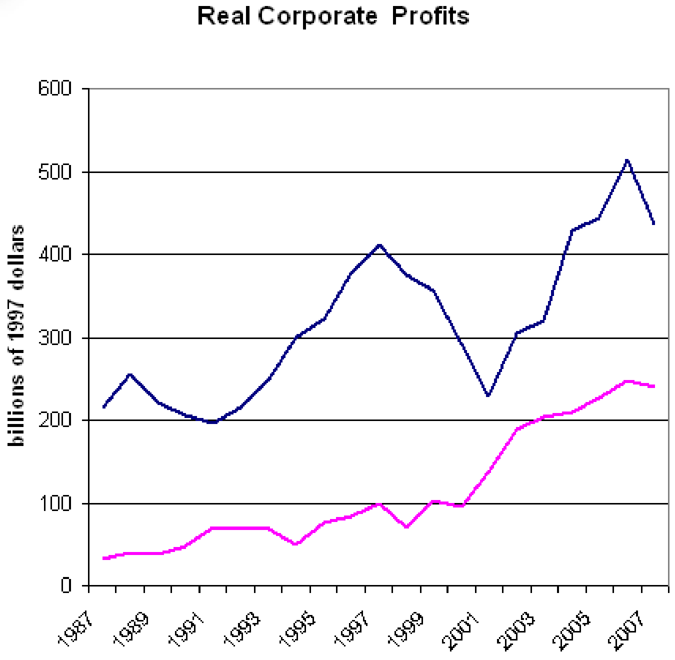


Source: IMF Global Financial Stability Report; World Economic Outlook November update and estimates; World Federation of Exchanges.

Dragon-king hypothesis

- Most crises are "endogenous"
  - ★ can be diagnosed in advance, can be quantified, (some) predictability
- Moral hazard, conflict of interest, role of regulations
- Responsibility, accountability
- Strategic vs tactical time-dependent strategy
- Weak versus global signals

POSITIVE FEEDBACKS



After-tax domestic corporate profits with inventory and capital cost adjustments

http://www.businessweek.com/the_thread/economicsunbound/archives/2009/03/a_bad_decade_fo.html

Source: Philippon, 2008

Michael Mandel

Origin of the 2007-XXXX crisis:
20y History of bubbles and Dragon-kings

- Crises are the “norm” rather than the exception
- Crises are often the consequence of excess leverage, i.e., bubbles
- Bubbles results from procyclical positive feedbacks
- Nonlinear stochastic finite-singular processes
- Possibility of developing probabilistic warning

1) diagnostic of bubbles

2) forecast of change of regime (burst)

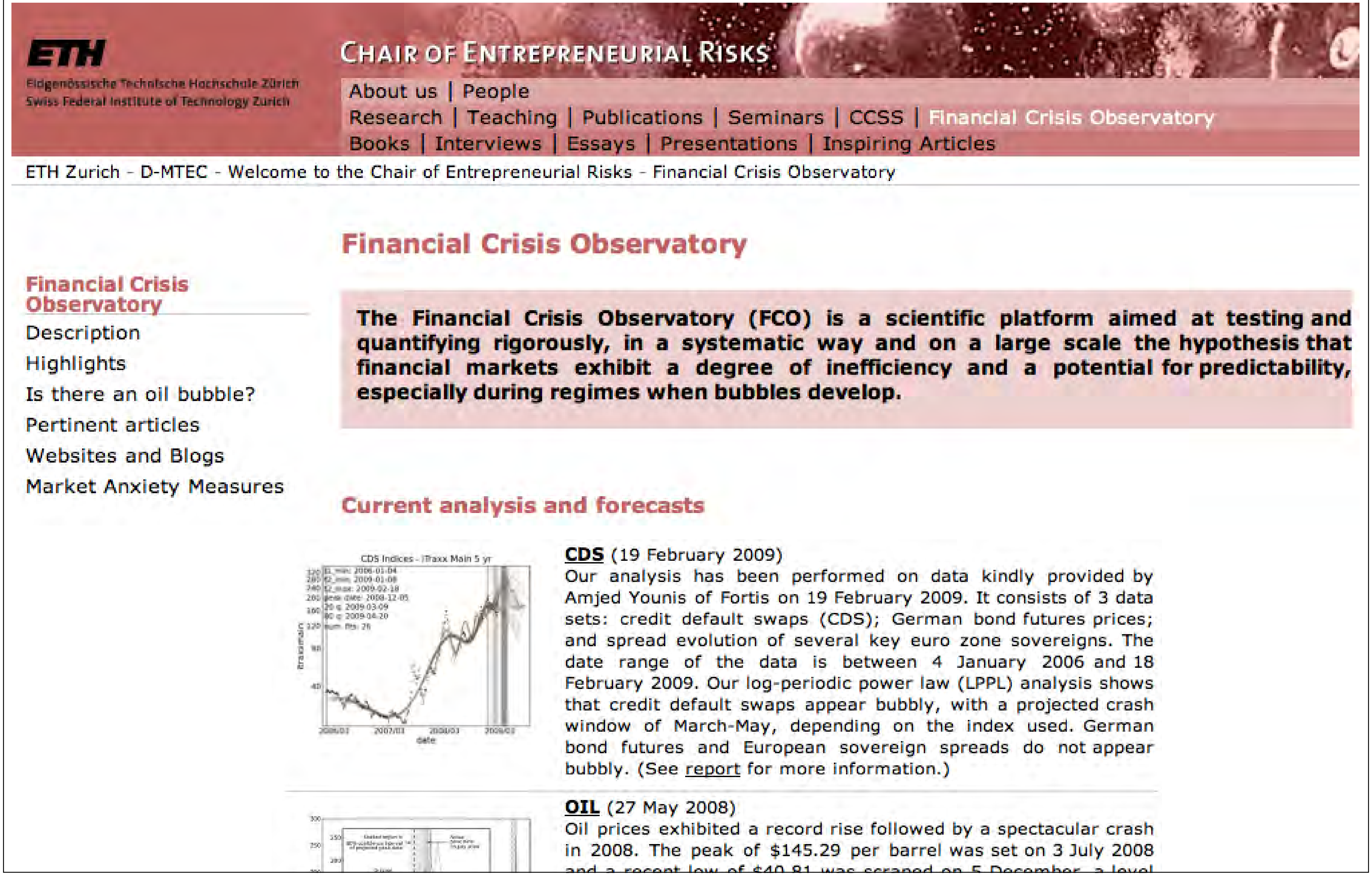
Origin of the 2007-XXXX crisis:
20y History of bubbles and Dragon-kings

- **The ITC "new economy" bubble (1995-2000)**
- **Slaving of the Fed monetary policy to the stock market descent (2000-2003)**
- **Real-estate bubbles (2003-2006)**
- **MBS, CDOs bubble (2004-2007)**
- **Stock market bubble (2004-2007)**
- **Commodities and Oil bubbles (2006-2008)**

Didier Sornette and Ryan Woodard
Financial Bubbles, Real Estate bubbles, Derivative Bubbles, and the Financial and Economic Crisis (2009)(http://arxiv.org/abs/0905.0220)

Financial Crisis Observatory

www.er.ethz.ch/fco



CHAIR OF ENTREPRENEURIAL RISKS

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Books | Interviews | Essays | Presentations | Inspiring Articles

ETH Zurich - D-MTEC - Welcome to the Chair of Entrepreneurial Risks - Financial Crisis Observatory

Financial Crisis Observatory

- Description
- Highlights
- Is there an oil bubble?
- Pertinent articles
- Websites and Blogs
- Market Anxiety Measures

Financial Crisis Observatory

The Financial Crisis Observatory (FCO) is a scientific platform aimed at testing and quantifying rigorously, in a systematic way and on a large scale the hypothesis that financial markets exhibit a degree of inefficiency and a potential for predictability, especially during regimes when bubbles develop.

Current analysis and forecasts

CDS (19 February 2009)
Our analysis has been performed on data kindly provided by Amjed Younis of Fortis on 19 February 2009. It consists of 3 data sets: credit default swaps (CDS); German bond futures prices; and spread evolution of several key euro zone sovereigns. The date range of the data is between 4 January 2006 and 18 February 2009. Our log-periodic power law (LPPL) analysis shows that credit default swaps appear bubbly, with a projected crash window of March-May, depending on the index used. German bond futures and European sovereign spreads do not appear bubbly. (See report for more information.)

OIL (27 May 2008)
Oil prices exhibited a record rise followed by a spectacular crash in 2008. The peak of $145.29 per barrel was set on 3 July 2008

Methodology for diagnosing bubbles

- Positive feedbacks of higher return anticipation
  - Super exponential price
  - Power law “Finite-time singularity”

- Negative feedback spirals of crash expectation
  - Accelerating large-scale financial volatility
  - Log-periodic discrete scale-invariant patterns

Imitation

Humans Appear Hardwired To Learn By 'Over-Imitation'

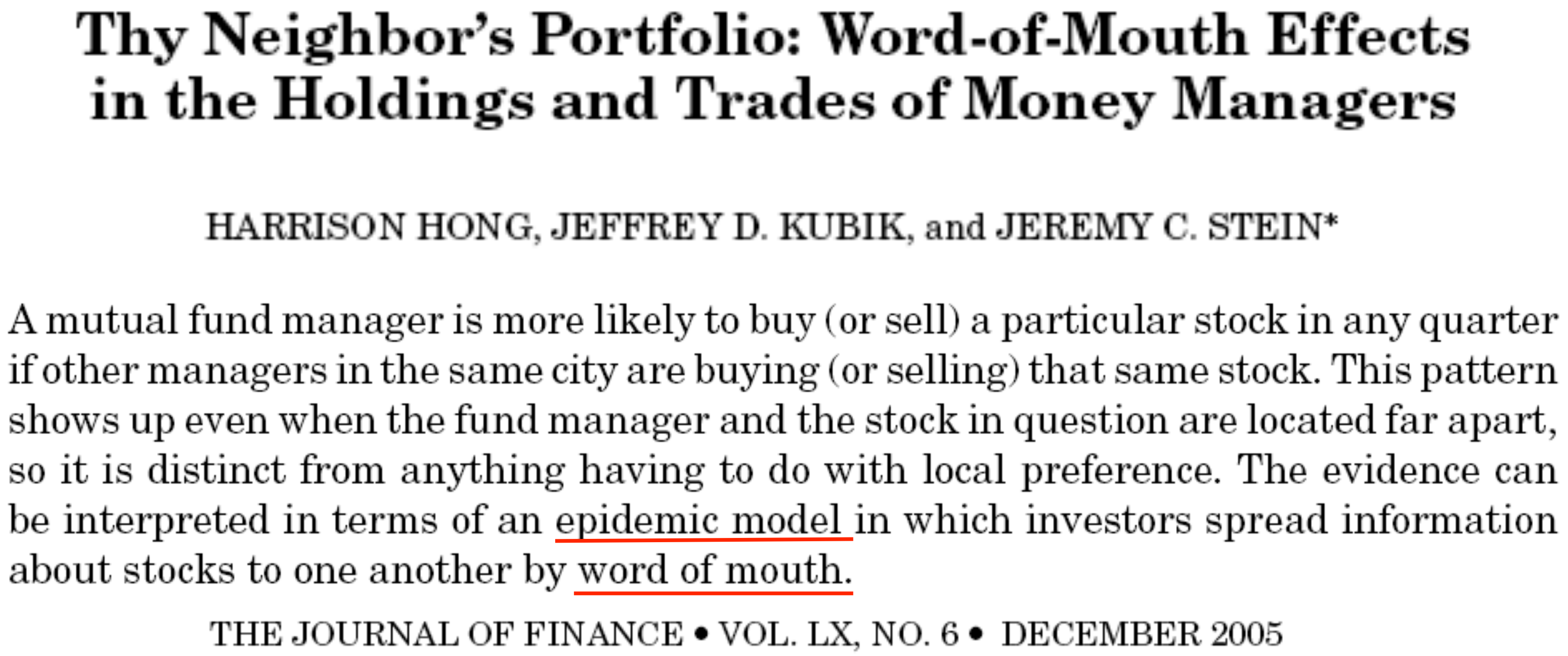
ScienceDaily (Dec. 6, 2007) — Children learn by imitating adults--so much so that they will rethink how an object works if they observe an adult taking unnecessary steps when using that object.

-Imitation is considered an efficient mechanism of social learning.

- Experiments in developmental psychology suggest that infants use imitation to get to know persons, possibly applying a ‘like-me’ test (‘persons which I can imitate and which imitate me’).

- Imitation is among the most complex forms of learning. It is found in highly socially living species which show, from a human observer point of view, ‘intelligent’ behavior and signs for the evolution of traditions and culture (humans and chimpanzees, whales and dolphins, parrots).

- In non-natural agents as robots, tool for easing the programming of complex tasks or endowing groups of robots with the ability to share skills without the intervention of a programmer. Imitation plays an important role in the more general context of interaction and collaboration between software agents and human users.

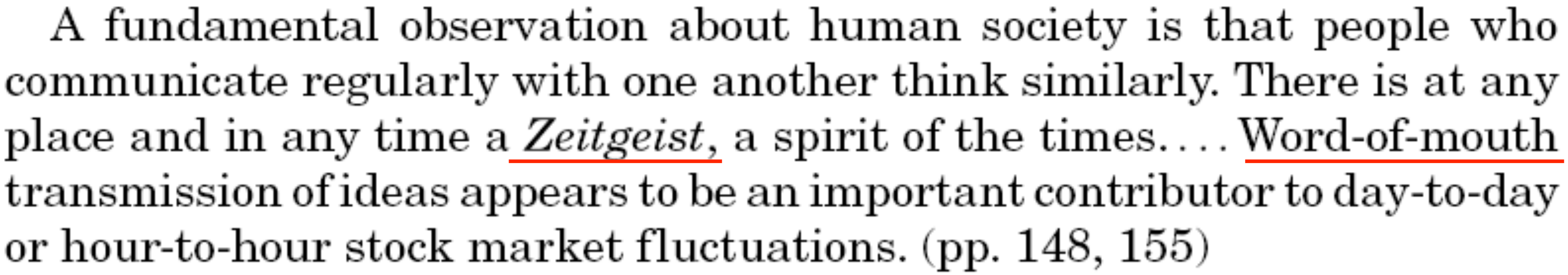


Thy Neighbor's Portfolio: Word-of-Mouth Effects in the Holdings and Trades of Money Managers

HARRISON HONG, JEFFREY D. KUBIK, and JEREMY C. STEIN*

A mutual fund manager is more likely to buy (or sell) a particular stock in any quarter if other managers in the same city are buying (or selling) that same stock. This pattern shows up even when the fund manager and the stock in question are located far apart, so it is distinct from anything having to do with local preference. The evidence can be interpreted in terms of an epidemic model in which investors spread information about stocks to one another by word of mouth.

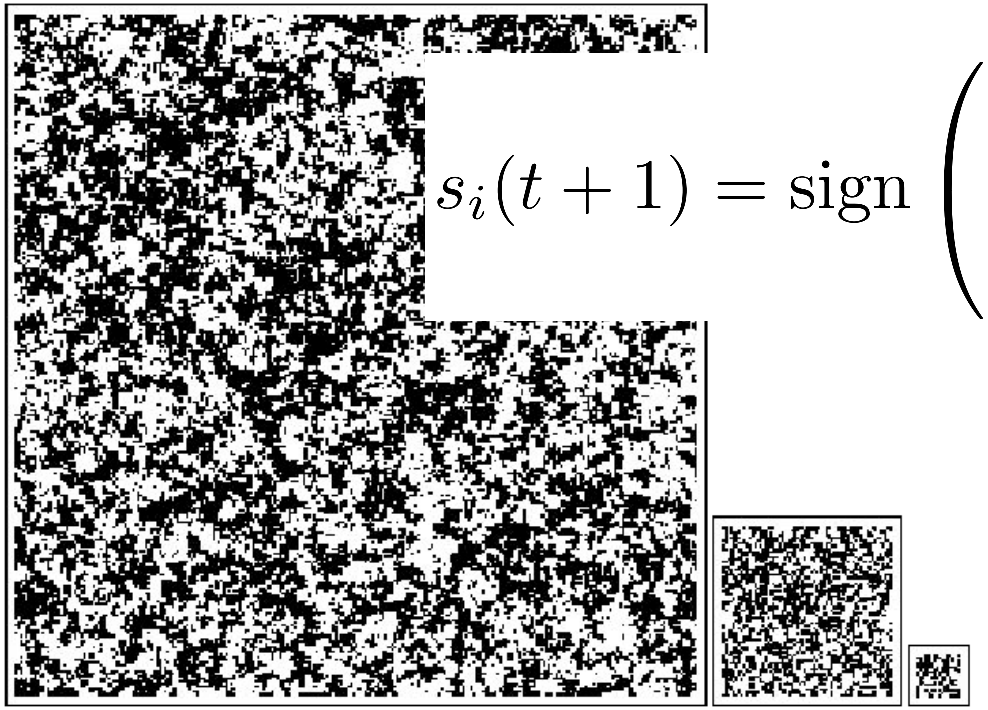
THE JOURNAL OF FINANCE • VOL. LX, NO. 6 • DECEMBER 2005



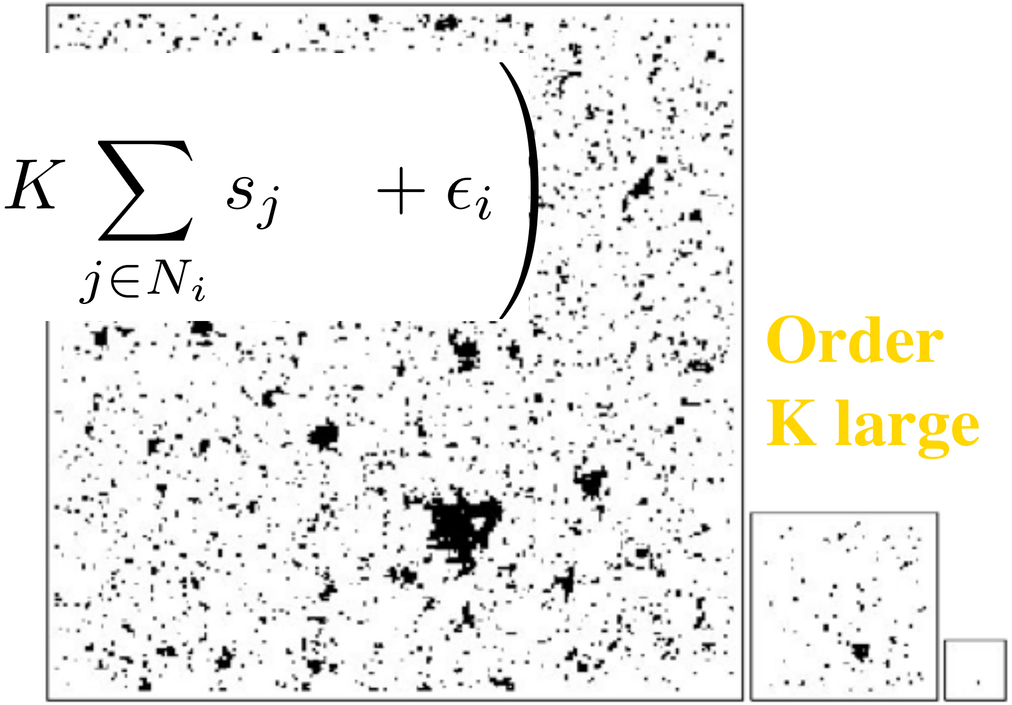
A fundamental observation about human society is that people who communicate regularly with one another think similarly. There is at any place and in any time a *Zeitgeist*, a spirit of the times. . . . Word-of-mouth transmission of ideas appears to be an important contributor to day-to-day or hour-to-hour stock market fluctuations. (pp. 148, 155)

Shiller (2000)

$$s_i(t+1) = \mathrm{sign}\left(K \sum_{j \in N_i} s_j \quad + \epsilon_i \right)$$



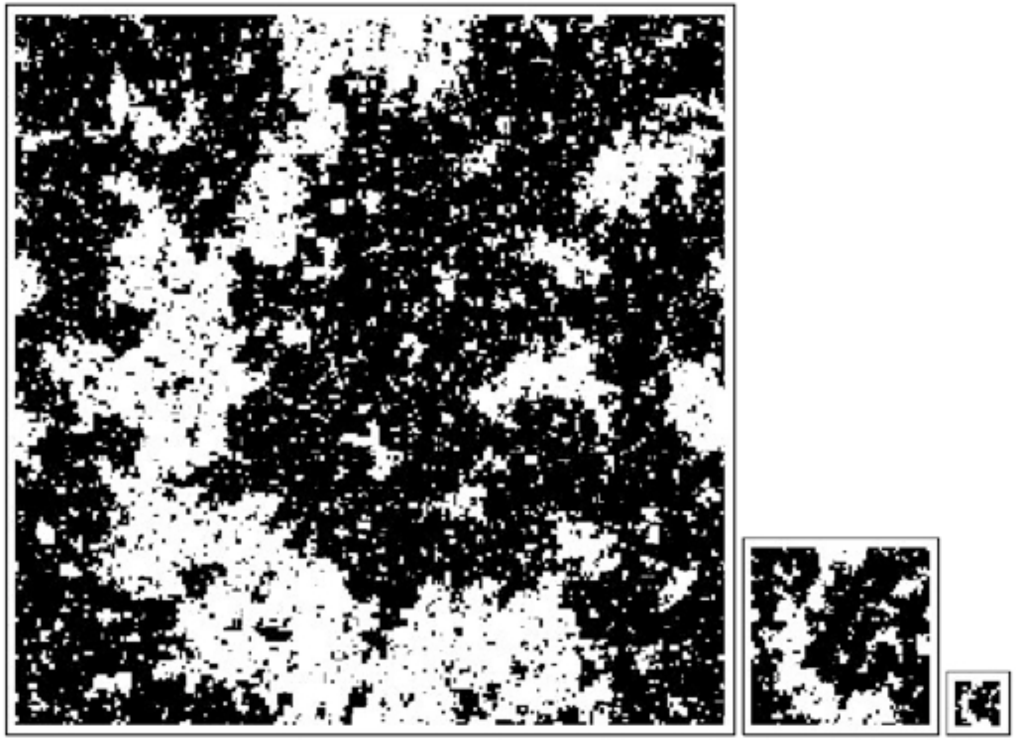
Disorder : K small



Order
K large

Renormalization group:
Organization of the description scale by scale

Critical:
K=critical value



Importance of Positive Feedbacks and Over-confidence in a Self-Fulfilling Ising Model of Financial Markets

$$s_i(t) = \text{sign}\left[\sum_{j\in\mathcal{N}} K_{ij}(t)\mathrm{E}[s_j](t) + \sigma_i(t)G(t) + \epsilon_i(t)\right]$$

Imitation **News** **Private information**

$$K_{ij}(t) = b_{ij} + \alpha_i K_{ij}(t-1) + \beta r(t-1)G(t-1)$$

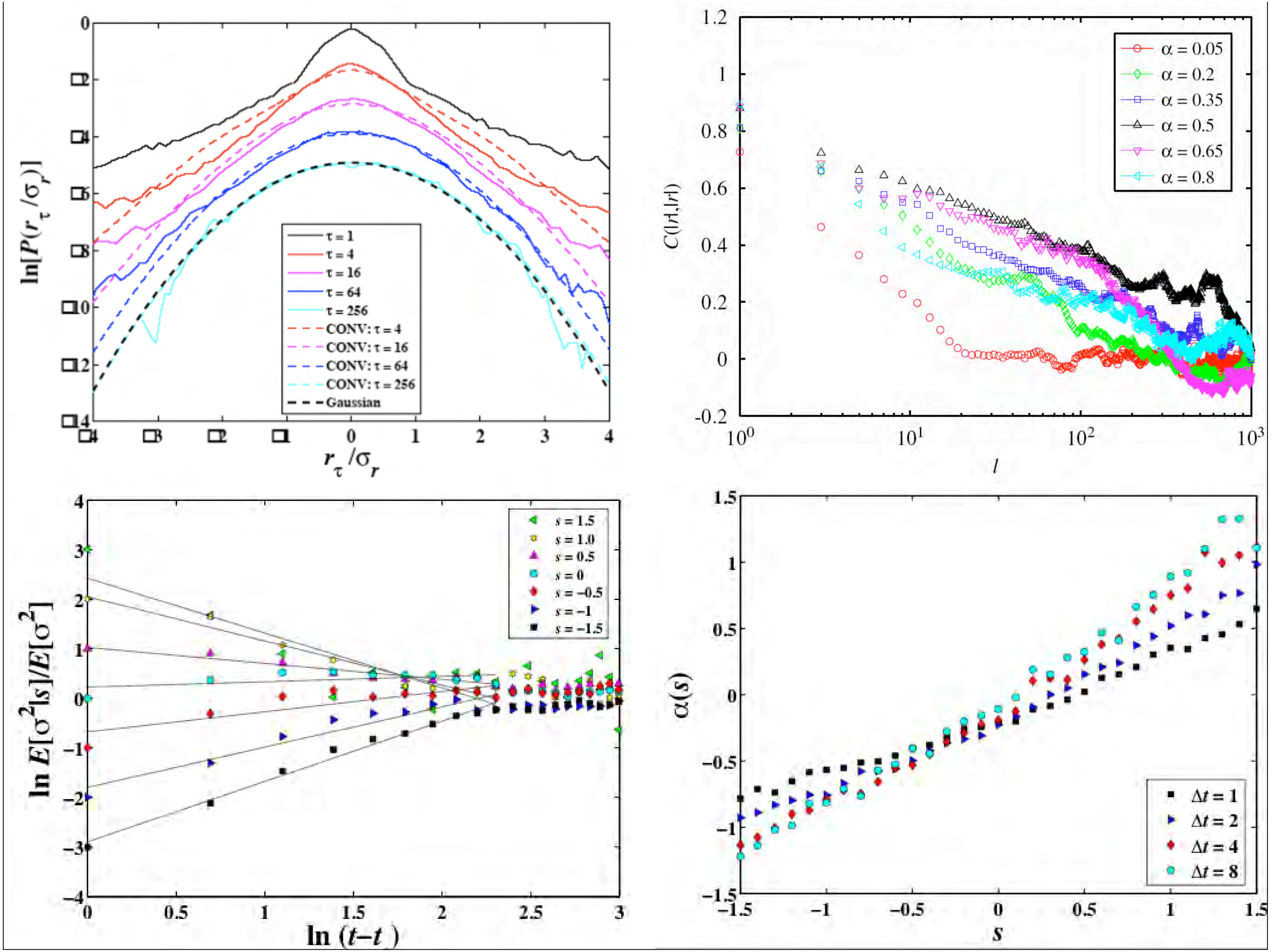
(generalizes Carlos Pedro Gonçalves, who generalized Johansen-Ledoit-Sornette)

β: propensity to be influenced by the felling of others

1. **$\beta<0$: rational agents**

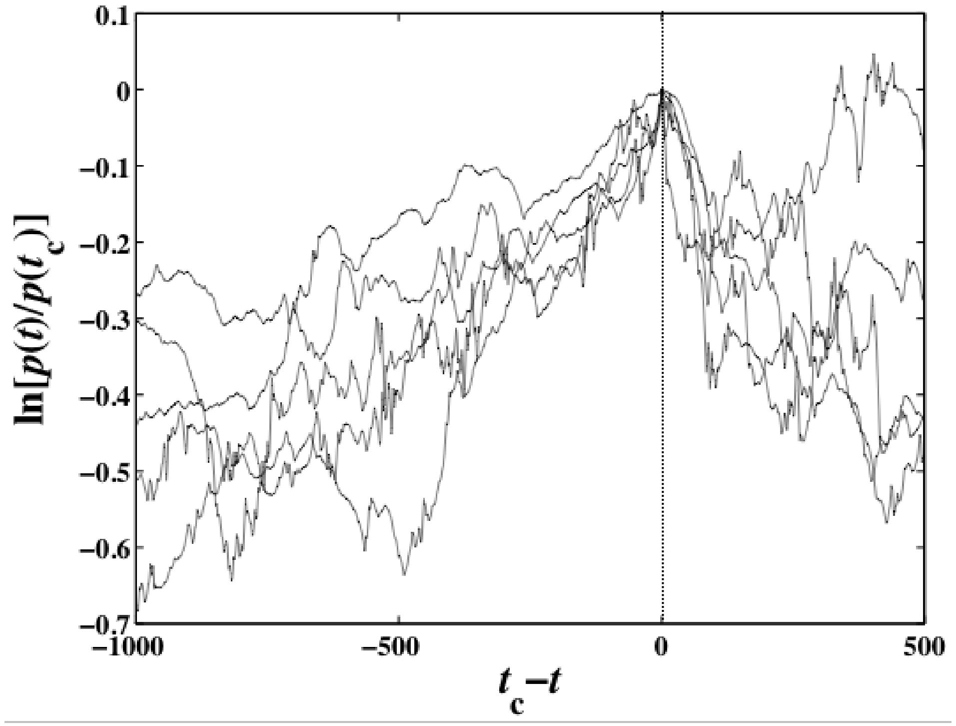
- **$\beta>0$: over-confident agents**

Didier Sornette and Wei-Xing Zhou, Physica A 370 (2), 704-726 (2006)


ln[P(r_τ/σ_r)]
r_τ/σ_r
0
−2
−4
−6
−8
−10
−12
−14
−4
−3
−2
−1
0
1
2
3
4
τ = 1
τ = 4
τ = 16
τ = 64
τ = 256
CONV: τ = 4
CONV: τ = 16
CONV: τ = 64
CONV: τ = 256
Gaussian
C(|r|,|r|)
l
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
10^0
10^1
10^2
10^3
α = 0.05
α = 0.2
α = 0.35
α = 0.5
α = 0.65
α = 0.8
ln E[σ²|s]/E[σ²]
ln (t−t)
4
3
2
1
0
-1
-2
-3
-4
0
0.5
1
1.5
2
2.5
3
s = 1.5
s = 1.0
s = 0.5
s = 0
s = −0.5
s = −1
s = −1.5
α(s)
s
1.5
1
0.5
0
−0.5
−1
−1.5
−1.5
−1
−0.5
0
0.5
1
1.5
Δt = 1
Δt = 2
Δt = 4
Δt = 8

Bubbles and crashes

Fig. 15. Five price trajectories showing bubbles preceding crashes that occur at the shifted time 0. The five time series have been translated so that the time of their crash is placed at the origin $t = 0$.



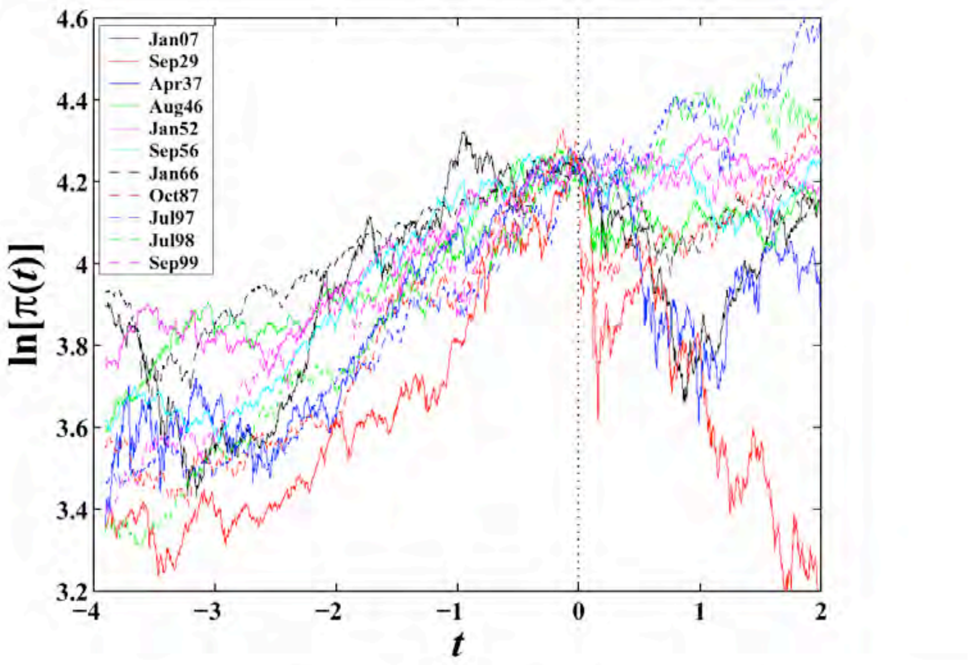
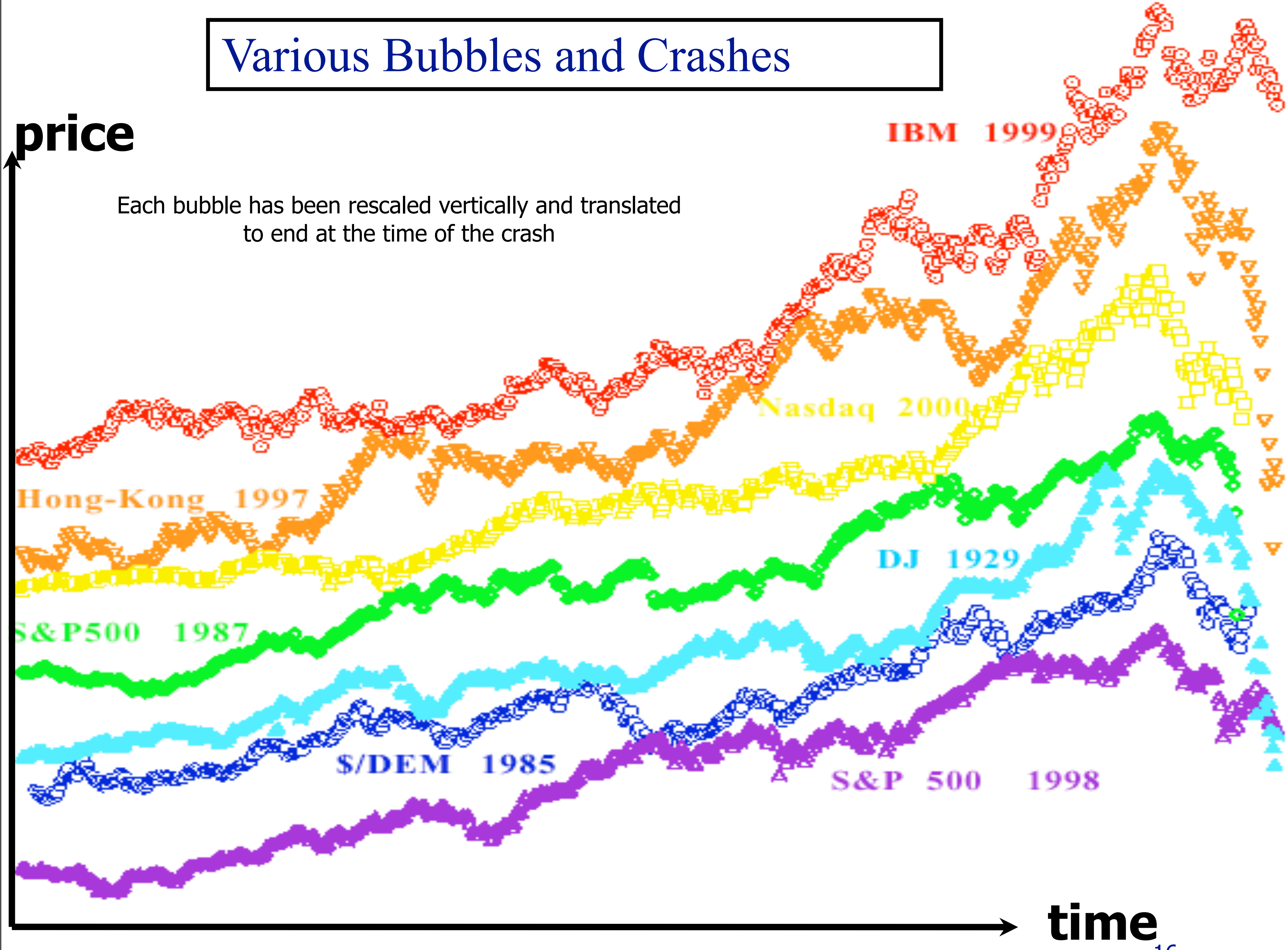


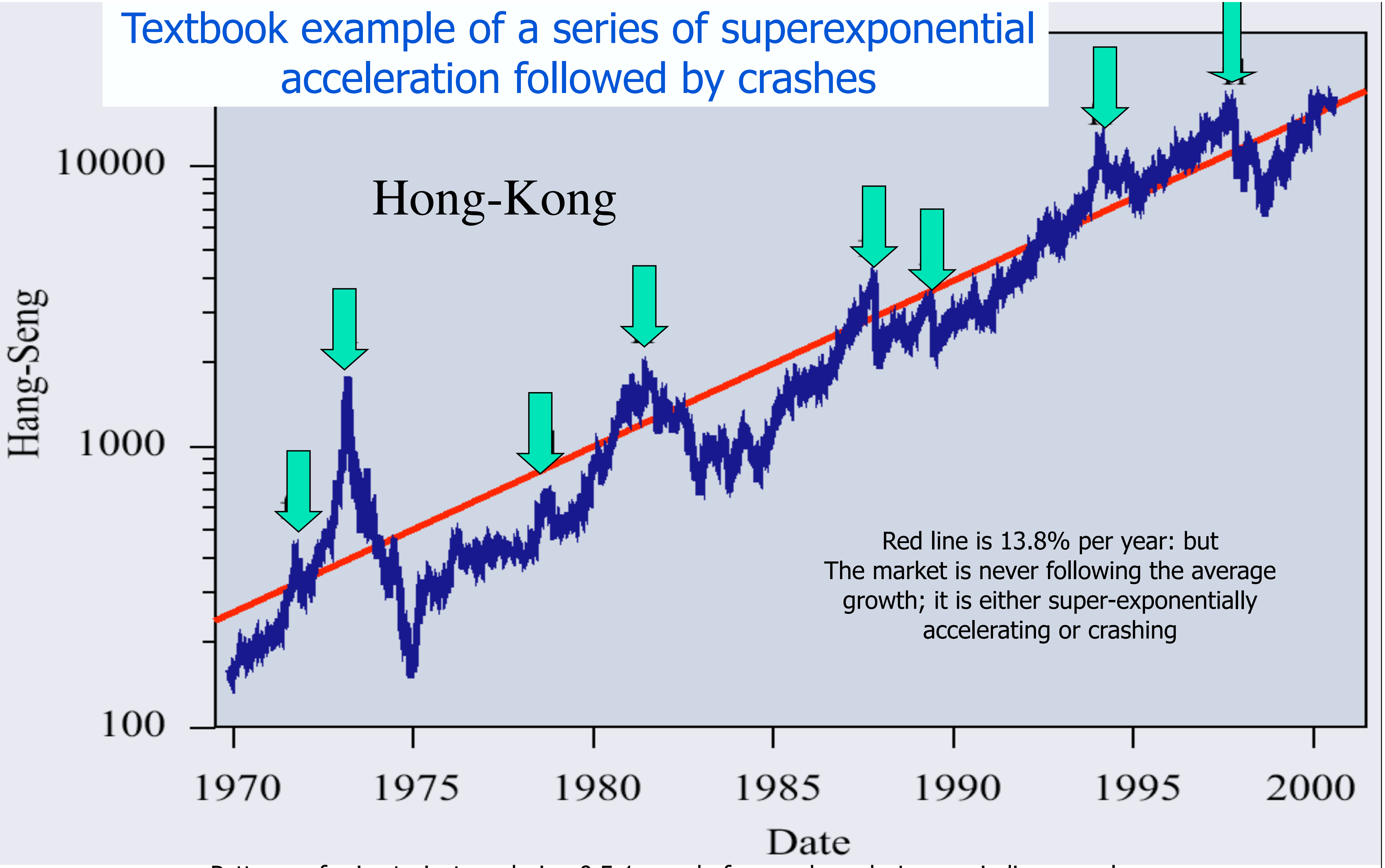
Figure 4: (Color online) Superposed epoch analysis of the 11 time intervals, each of 6 years long, of the DJIA index centered on the time of the maxima of the 11 predictor peaks above $AI = 0.3$ of the alarm index shown in Fig. 3.

D. Sornette and W.-X. Zhou
Predictability of Large Future Changes in major financial indices,
International Journal of Forecasting 22, 153-168 (2006)

Various Bubbles and Crashes

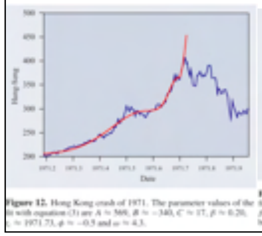
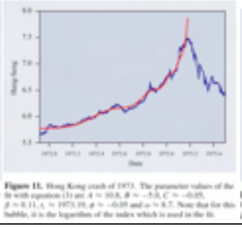
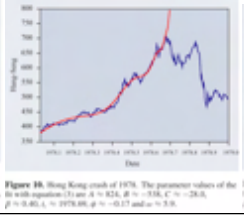
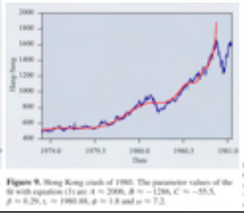
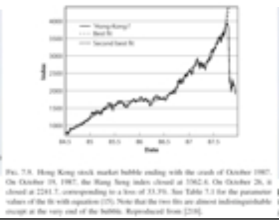
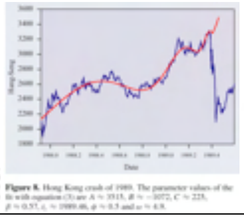
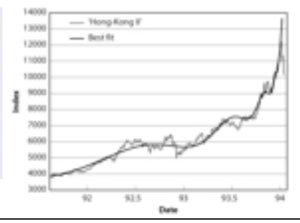
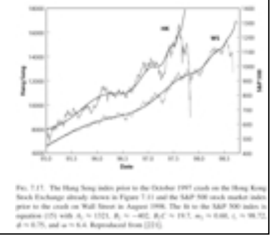


Textbook example of a series of superexponential acceleration followed by crashes



Red line is 13.8% per year: but
The market is never following the average growth; it is either super-exponentially accelerating or crashing

Patterns of price trajectory during 0.5-1 year before each peak: Log-periodic power law

Positive feedbacks and finite-time singularity

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.

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

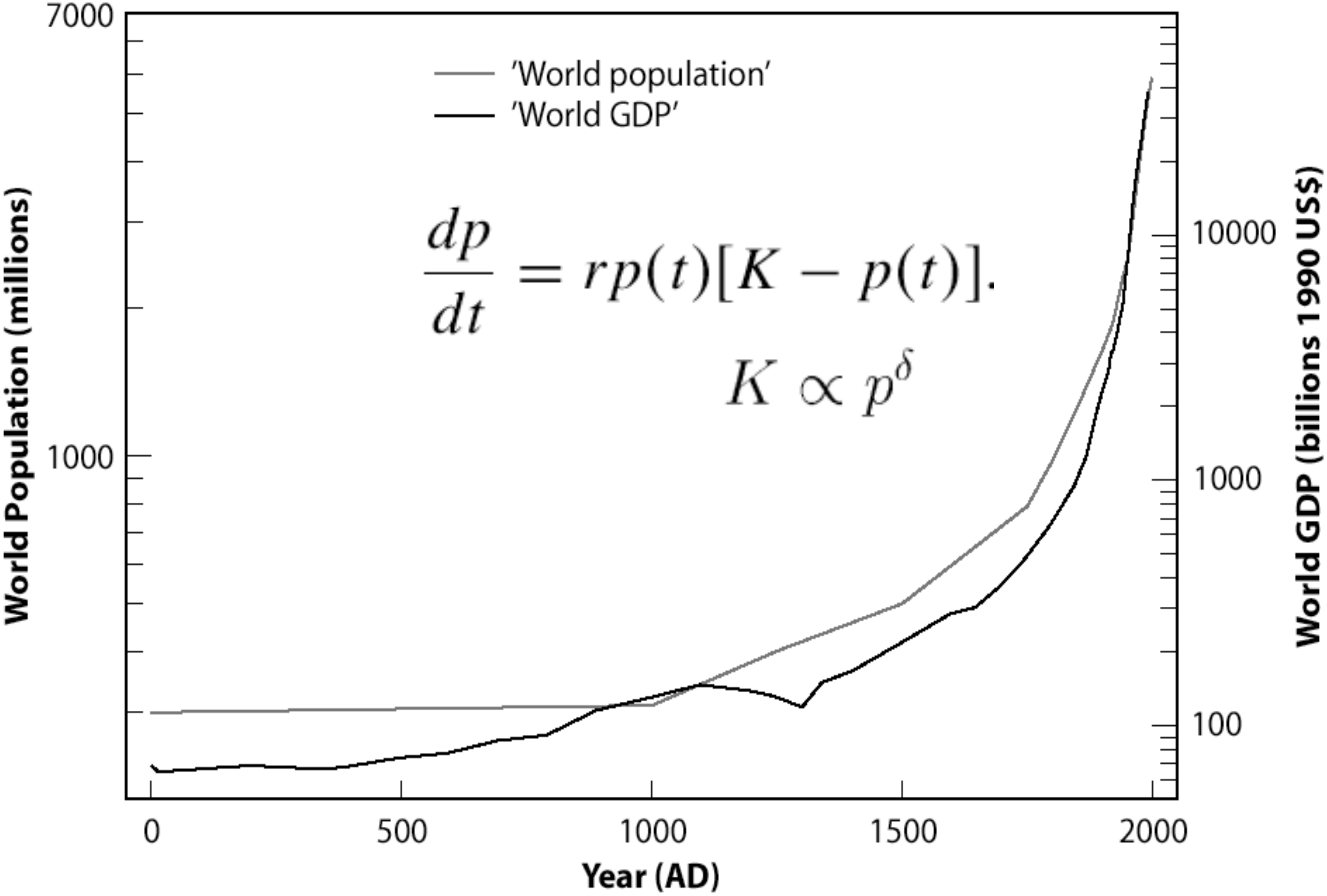
$$\frac{dp}{dt} = r[p(t)]^{1+\delta};$$

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



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

$$K \propto p^{\delta}$$

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)

DISCRETE HIERARCHY OF THE AGENT NETWORK

Presentation of three different mechanisms leading to discrete scale invariance, discrete hierarchies and log-periodic signatures

- ☐ Co-evolution of brain size and group size

  (Why do we have a big Brain?)

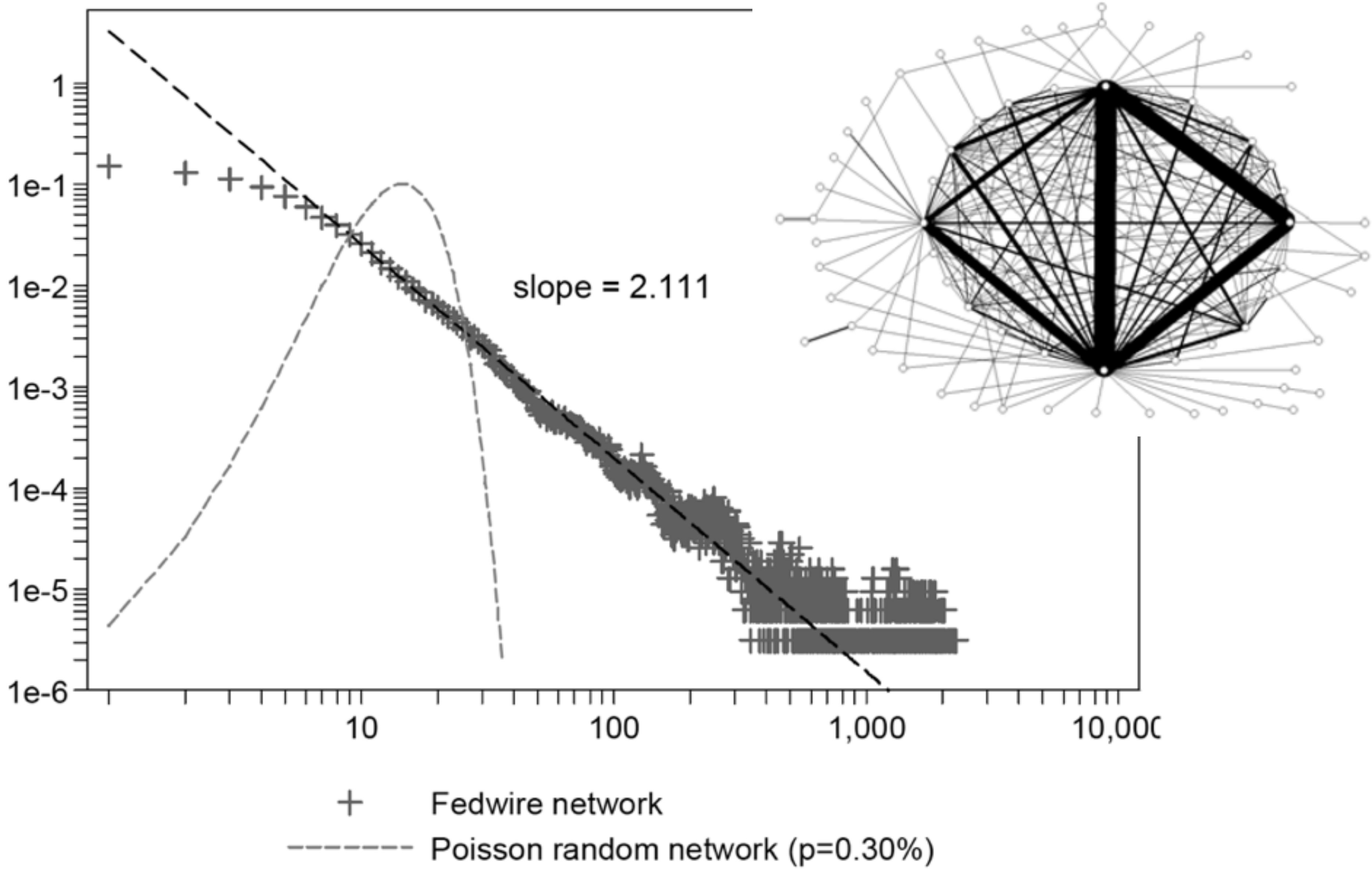
- ☐ Interplay between nonlinear positive and negative feedbacks and inertia

- ☐ Discrete scale invariance

  Complex fractal dimension

  Log-periodicity

network topology of the interbank payments transferred between commercial banks over the Fedwire® Funds Service

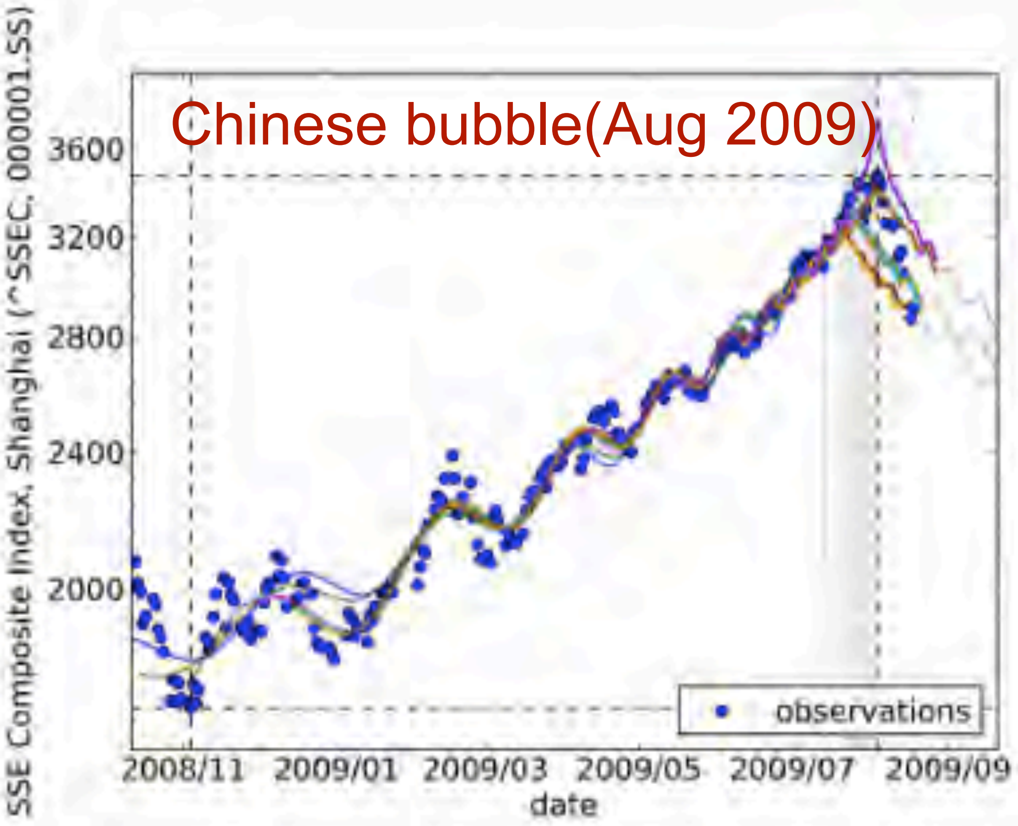


Kimmo Soramäki, Morten L. Bech, Jeffrey Arnold, Robert J. Glass, and Walter E. Beyeler, Physica A 379, 317-333 (2006)

FCO@ETH: Towards operational science of financial instabilities

Didier Sornette, Ryan Woodard, Peter Cauwels, Vladimir Filimonov, Wanfeng Yan, Qunzhi Zhang, Wei-Xing Zhou

- Main mission:
  - Identify bubbles
- Theory:
  - Positive feedback
- Deliverables
  - Weekly global bubble scan
  - Research, papers
  - Public forecasts
  - Digital timestamps


Chinese bubble(Aug 2009)

The Financial Bubble Experiment

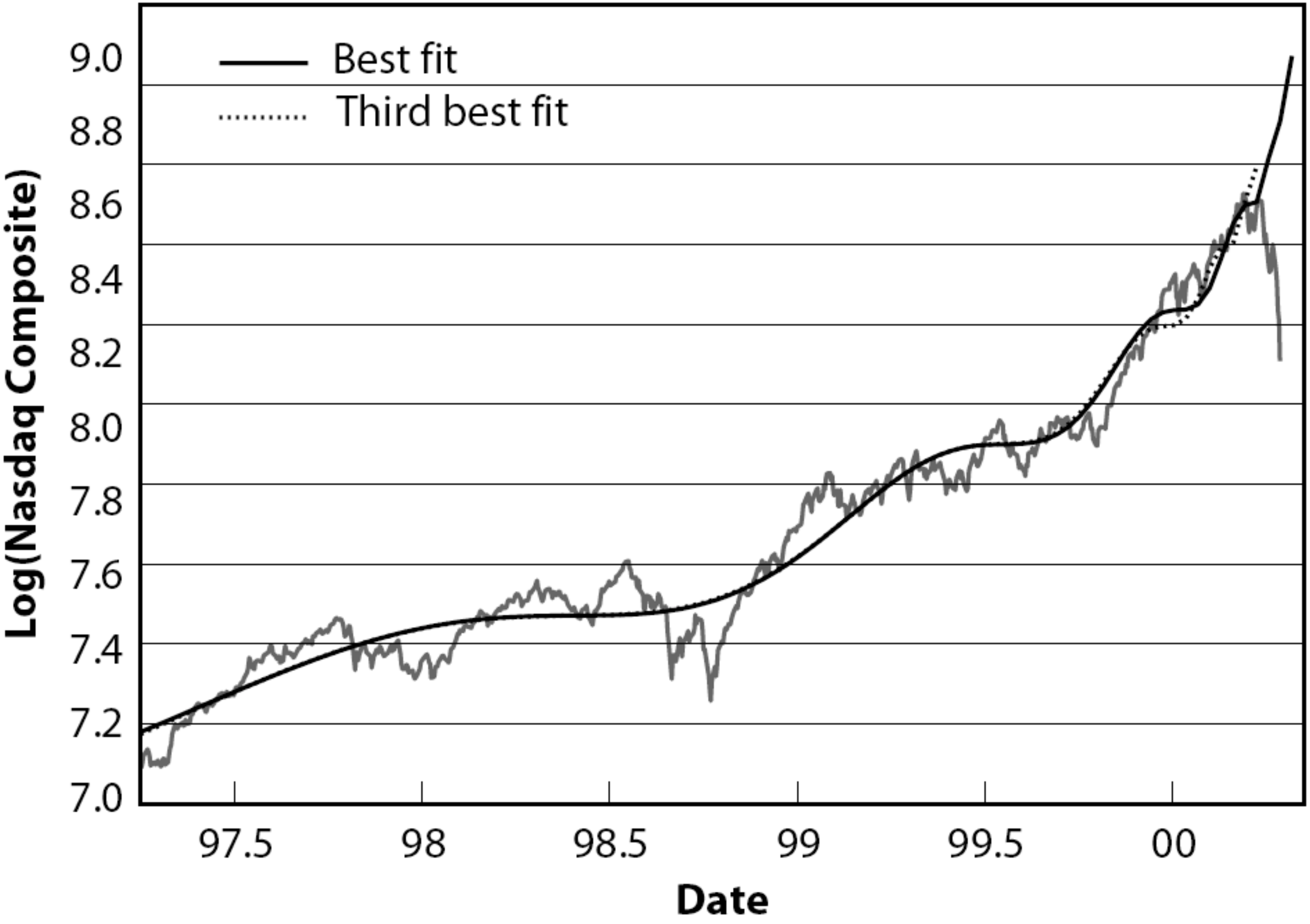
advanced diagnostics and forecasts of bubble terminations

- ***Hypothesis H1**: financial (and other) bubbles can be diagnosed in real-time before they end.*

- ***Hypothesis H2**: The termination of financial (and other) bubbles can be bracketed using probabilistic forecasts, with a reliability better than chance.*

THE NASDAQ CRASH OF APRIL 2000

“New Economy”: ICT



Real-estate in the UK

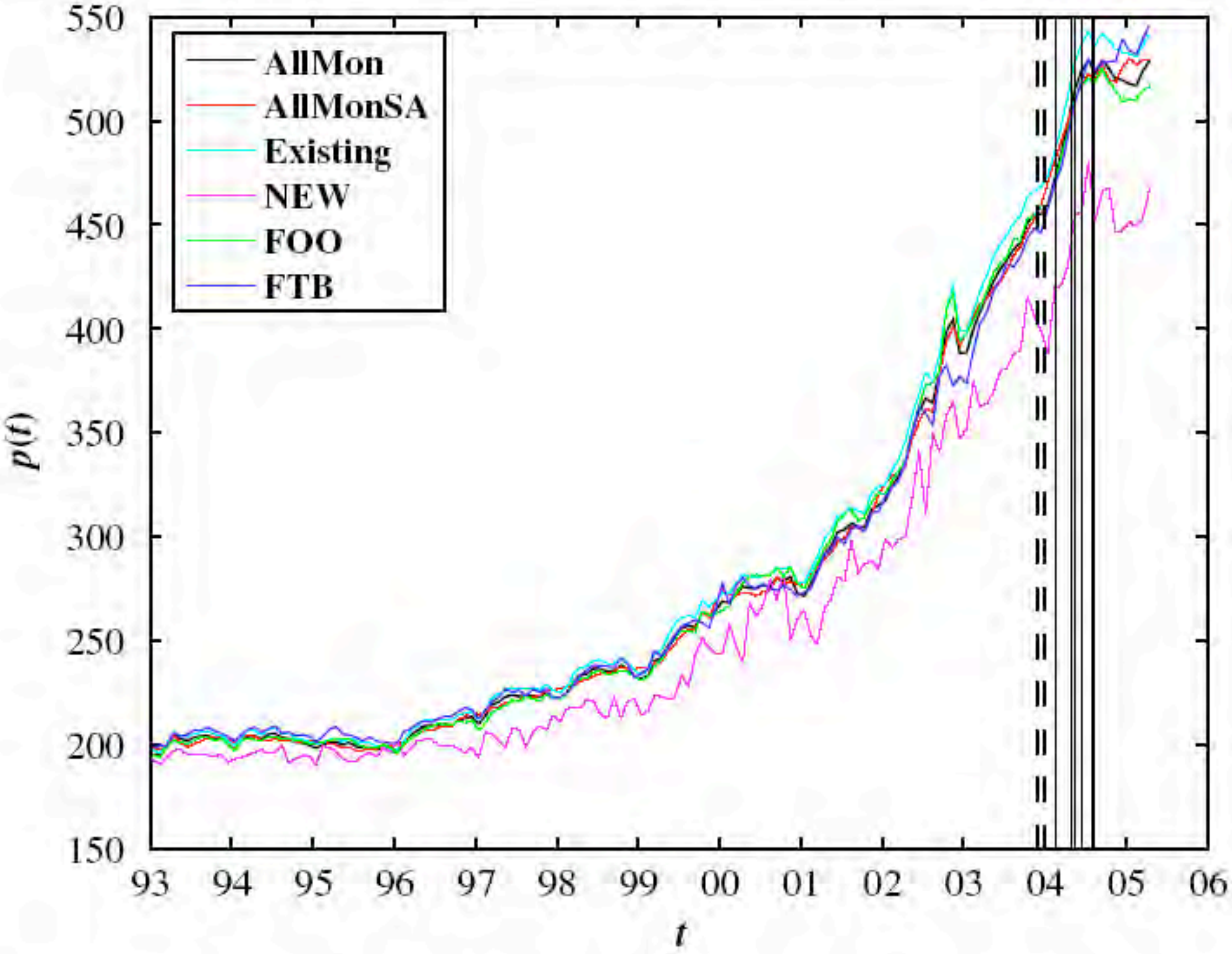


Fig. 1. (Color online) Plot of the UK Halifax house price indices from 1993 to April 2005 (the latest available quote at the time of writing). The two groups of vertical lines correspond to the two predicted turning points reported in Tables 2 and 3 of [1]: end of 2003 and mid-2004. The former (resp.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

W.-X. Zhou, D. Sornette, 2000–2003 real estate bubble in the UK but not in the USA, Physica A 329 (2003) 249–263.

Real-estate in the USA

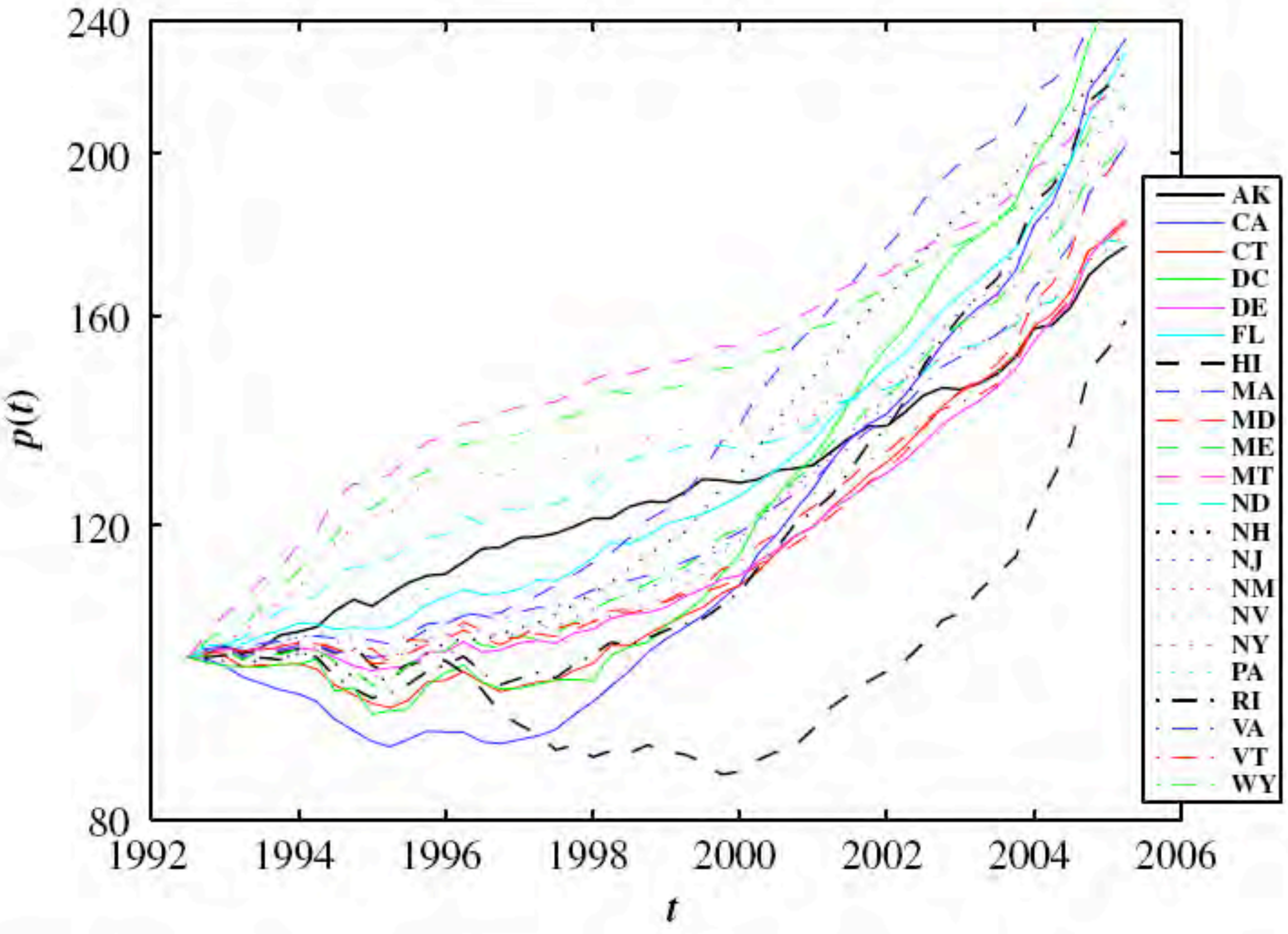
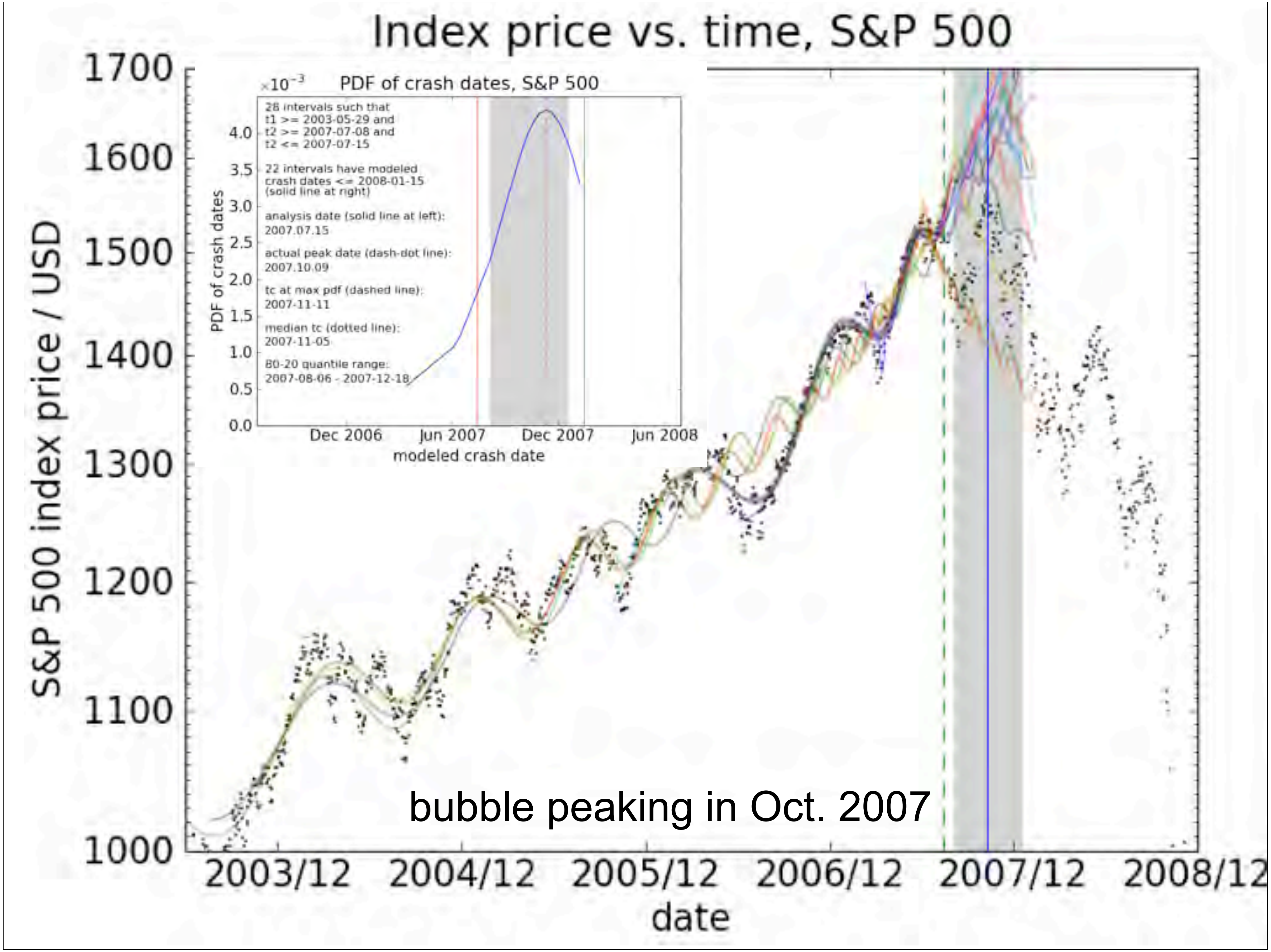


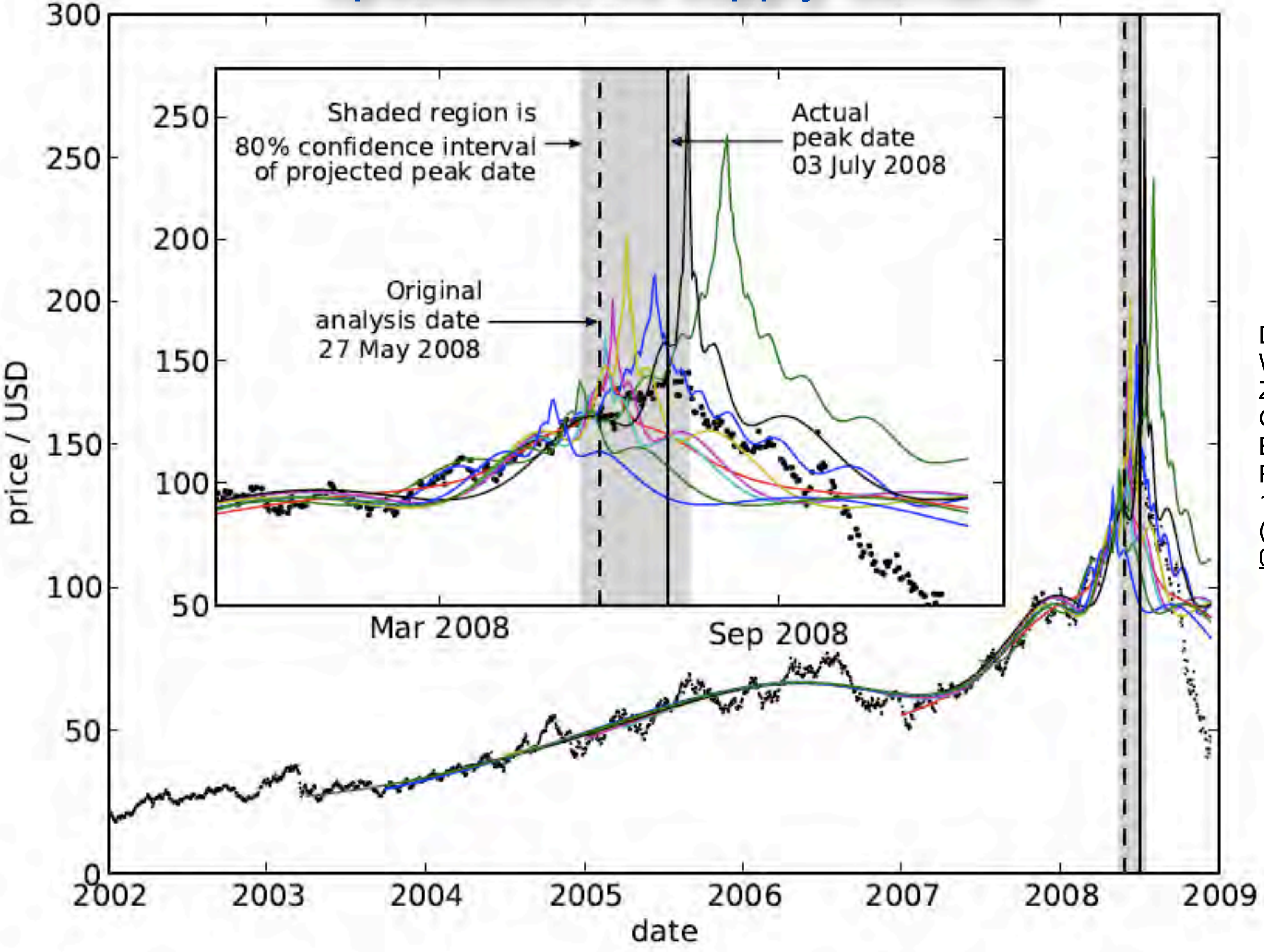
Fig. 5. (Color online) Quarterly average HPI in the 21 states and in the District of Columbia (DC) exhibiting a clear upward faster-than-exponential growth. For better representation, we have normalized the house price indices for the second quarter of 1992 to 100 in all 22 cases. The corresponding states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

W.-X. Zhou, D. Sornette / Physica A 361 (2006) 297–308



bubble peaking in Oct. 2007

2006-2008 Oil bubble
Speculation vs supply-demand

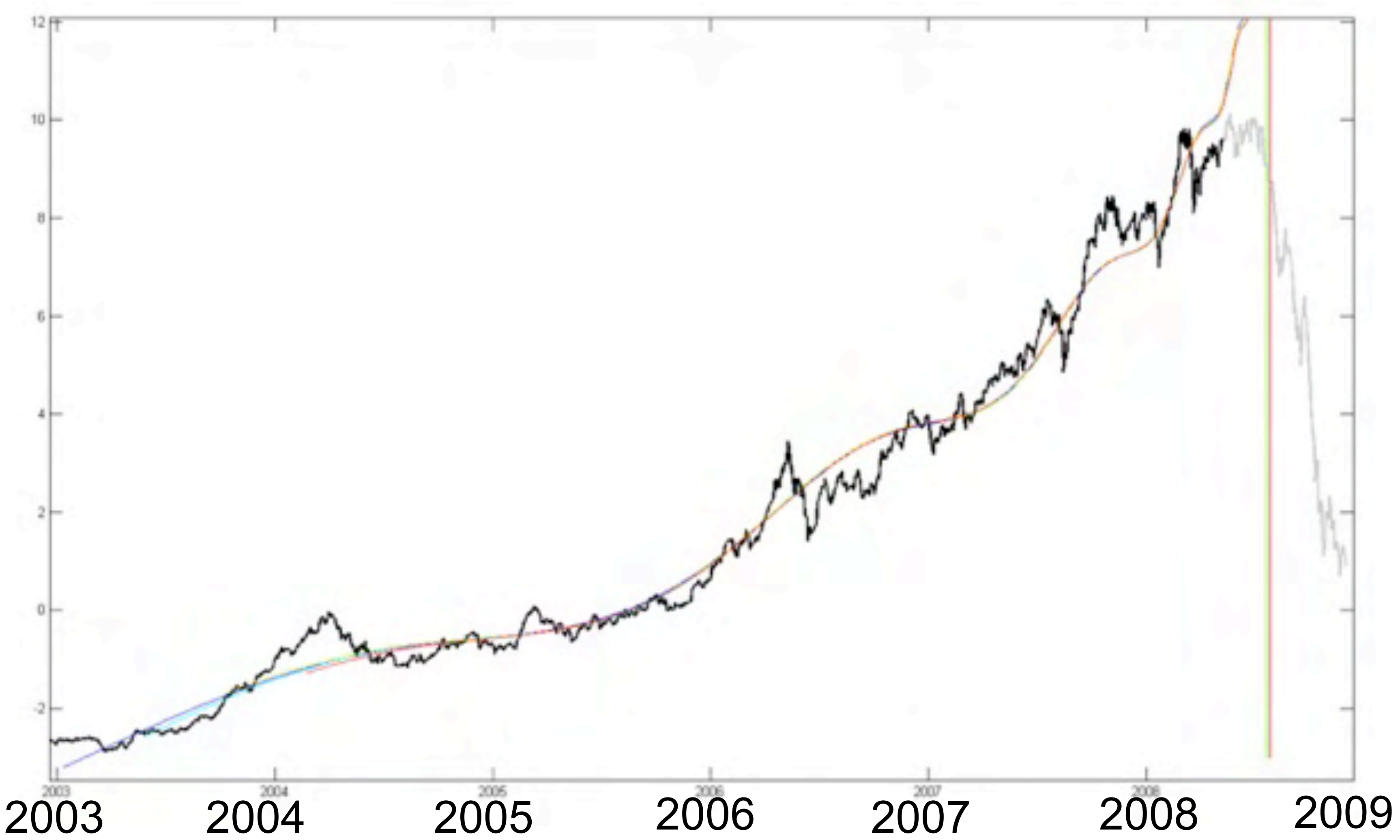


D. Sornette, R. Woodard and W.-X. Zhou, The 2006-2008 Oil Bubble and Beyond, Physica A 388, 1571-1576 (2009) (arXiv.org/abs/0806.1170)

Typical result of the calibration of the simple LPPL model to the oil price in US$ in shrinking windows with starting dates t_{start} moving up towards the common last date t_{last} = May 27, 2008.


Index price vs. time, Hang Seng
×10^4
Hang Seng index price / USD
3
2
1
2003/12
2004/12
2005/12
2006/12
2007/12
2008/12
date
×10^-3
PDF of crash dates, Hang Seng
28 intervals such that
t1 >= 2003-05-29 and
t2 >= 2007-07-08 and
t2 <= 2007-07-15
12 intervals have modeled
crash dates <= 2008-01-15
(solid line at right)
analysis date (solid line at left):
2007.07.15
actual peak date (dash-dot line):
2007.10.30
tc at max pdf (dashed line):
2007-10-04
median tc (dotted line):
2007-10-01
80-20 quantile range:
2007-08-31 - 2007-11-23
PDF of crash dates
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Dec 2006
Jun 2007
Dec 2007
Jun 2008
modeled crash date

The Global BUBBLE



PCA first component on a data set containing, emerging markets equity indices, freight indices, soft commodities, base and precious metals, energy, currencies...

(Peter Cauwels FORTIS BANK - Global Markets)

Out-of-equilibrium nonlinear financial economics

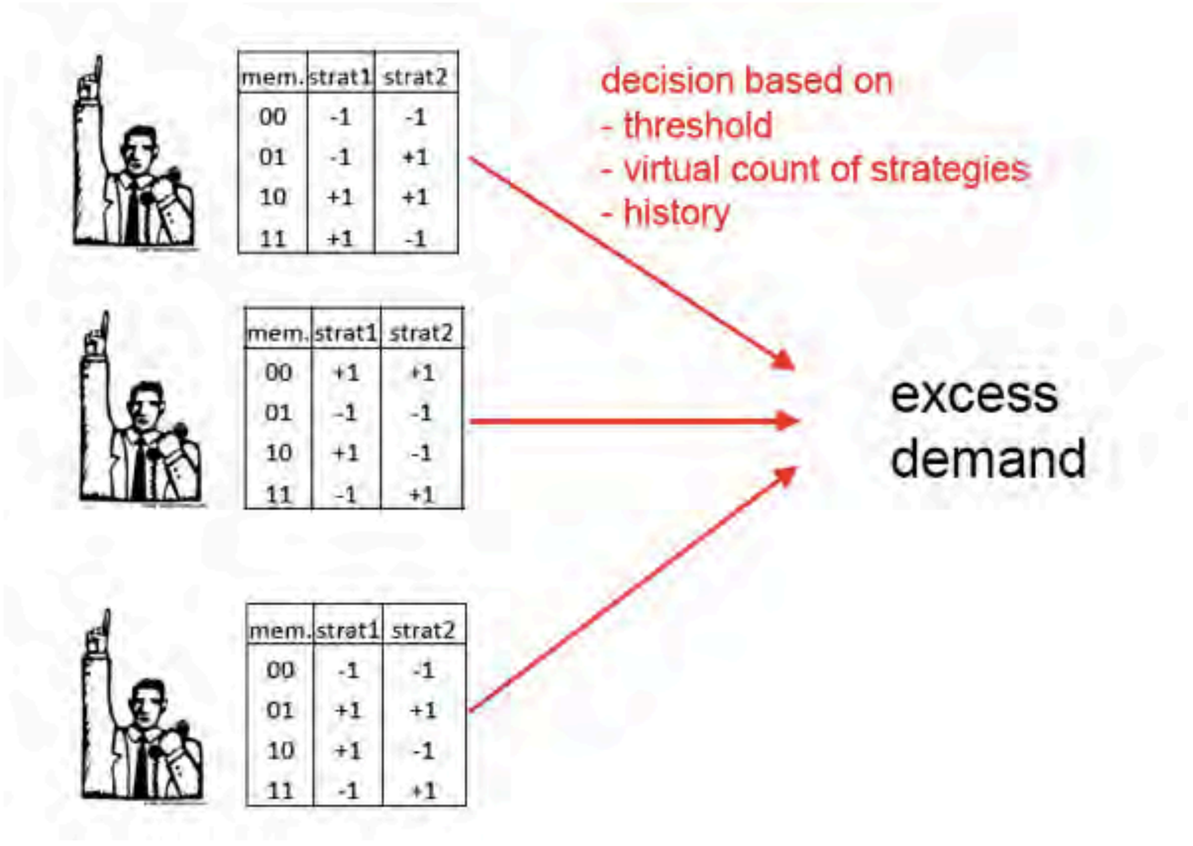
- Financial bubble experiments at ETH Zurich
- **Reverse engineering of financial markets with agent-based models**
- Illusion of control
- Multifractal endogenous econometric models for augmented variance estimators and forecasting
- Time-dependent lead-lag in econometrics
- Quantum decision theory

Goals

Get a scientific understanding of the generating process of a time series by finding 3rd Party Games (3rdPG) which produce similar time series to the one which is fed (insample)

→*Reverse Engineering*

Grand Canonical Minority Game (GCMG)



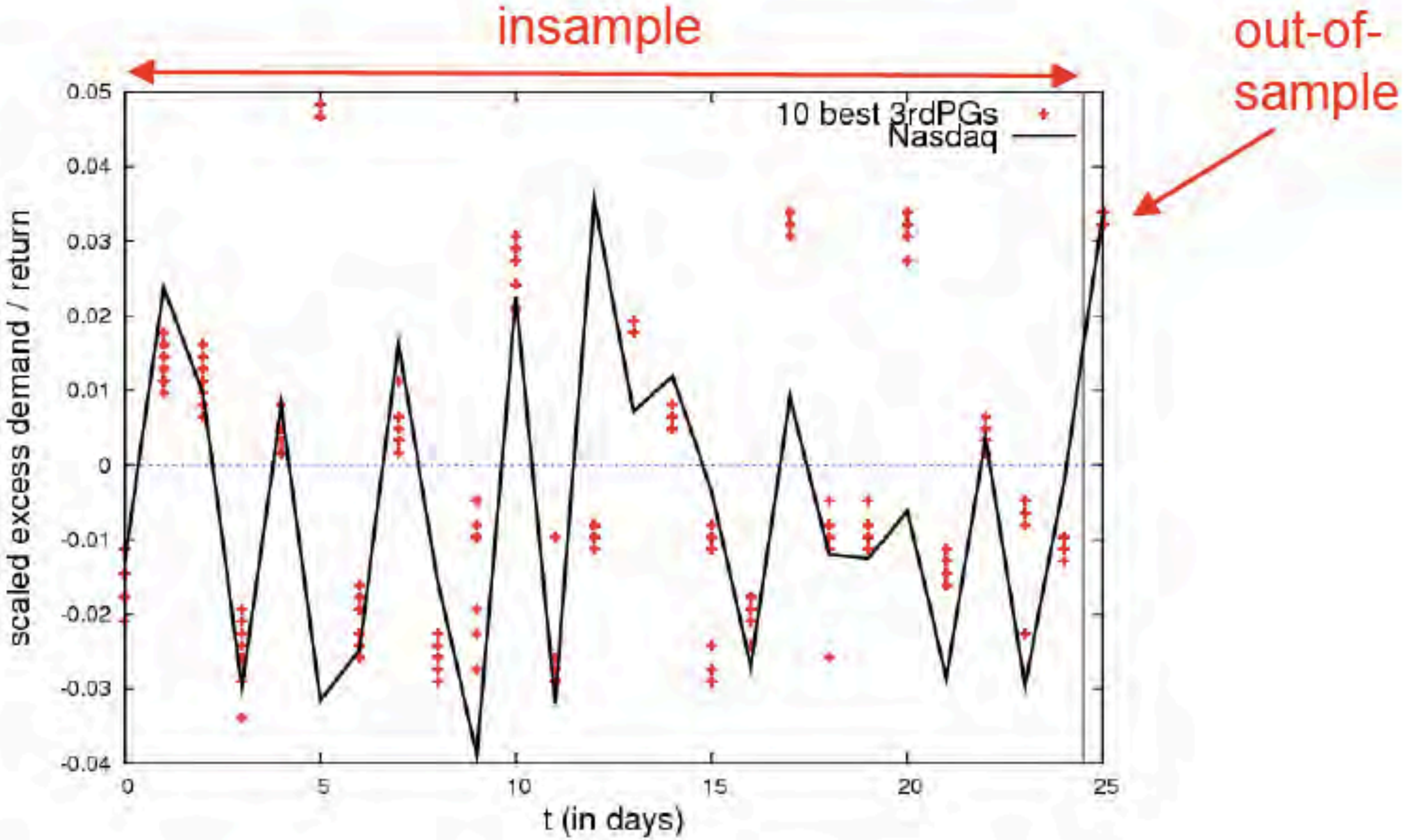
mem.	strat1	strat2
00	-1	-1
01	-1	+1
10	+1	+1
11	+1	-1

mem.	strat1	strat2
00	+1	+1
01	-1	-1
10	+1	-1
11	-1	+1

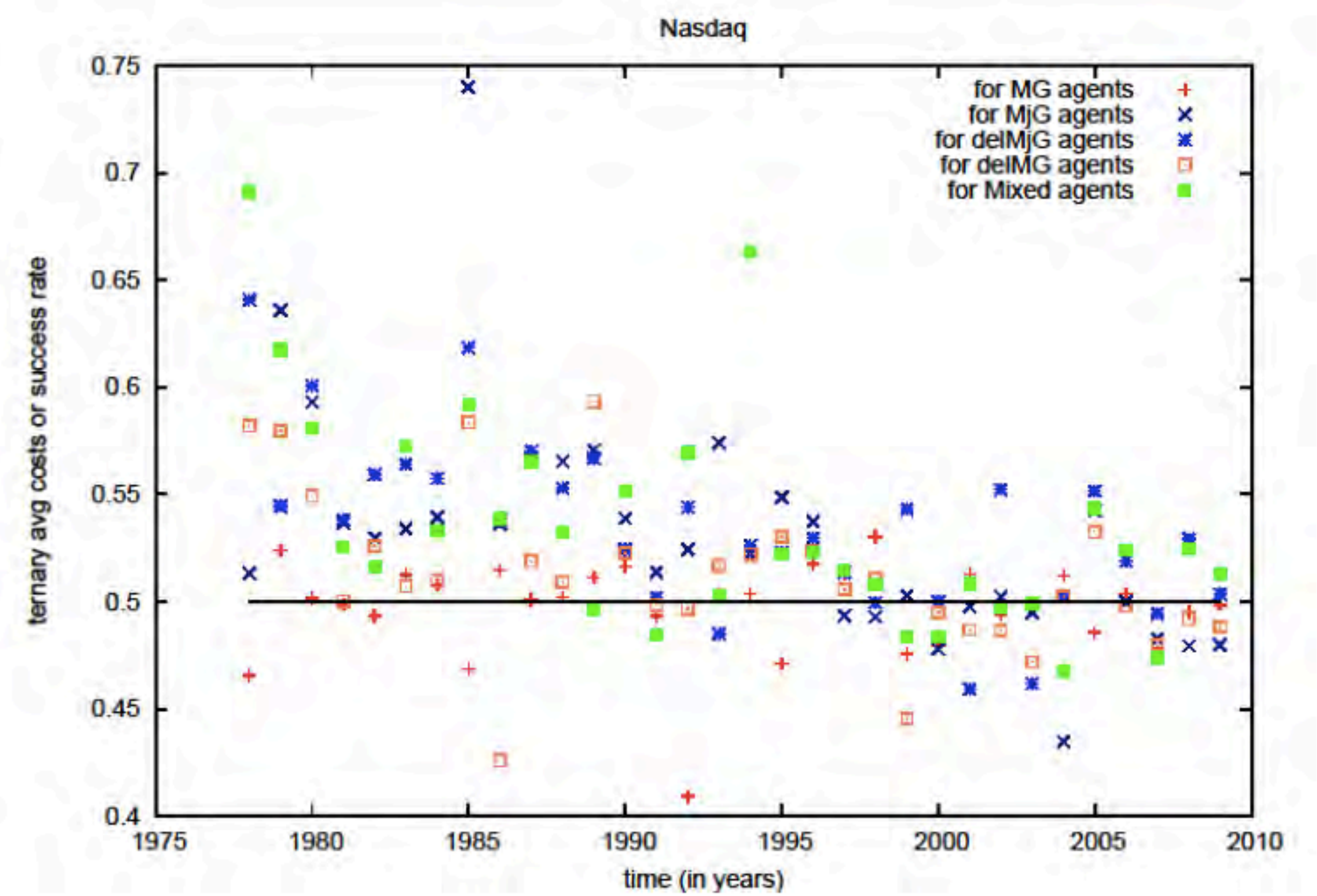
mem.	strat1	strat2
00	-1	-1
01	+1	+1
10	+1	-1
11	-1	+1

decision based on
- threshold
- virtual count of strategies
- history

Genetic Algorithm Optimization



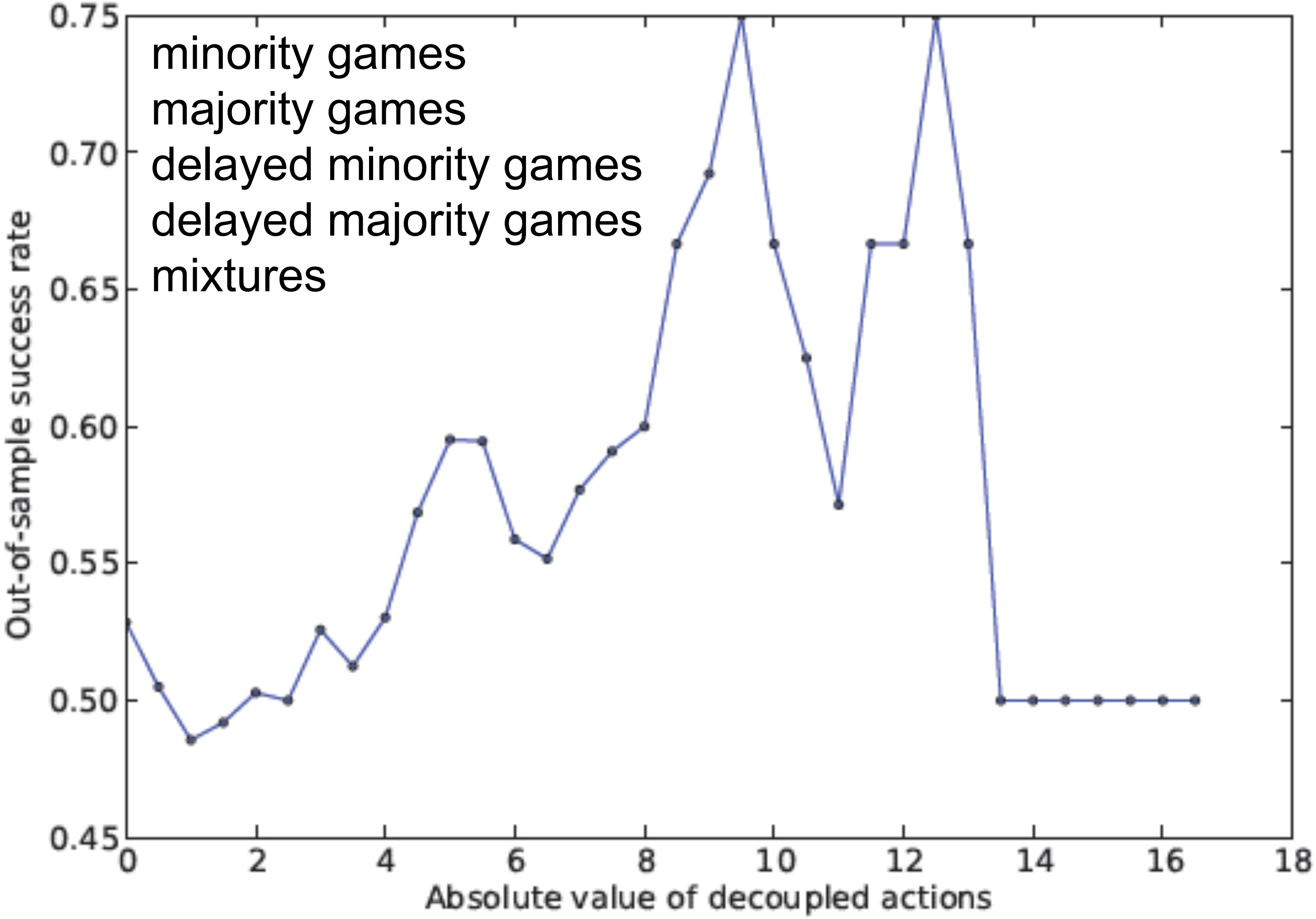
Result of Academic Interest:
Markets become more and more efficient



A Mechanism for Pockets of Predictability in Complex Adaptive Systems

J.V. Andersen and D. Sornette, Europhys. Lett., 70 (5), 697-703 (2005)

Novel developments with Qunzhi Zhang at ETH Zurich

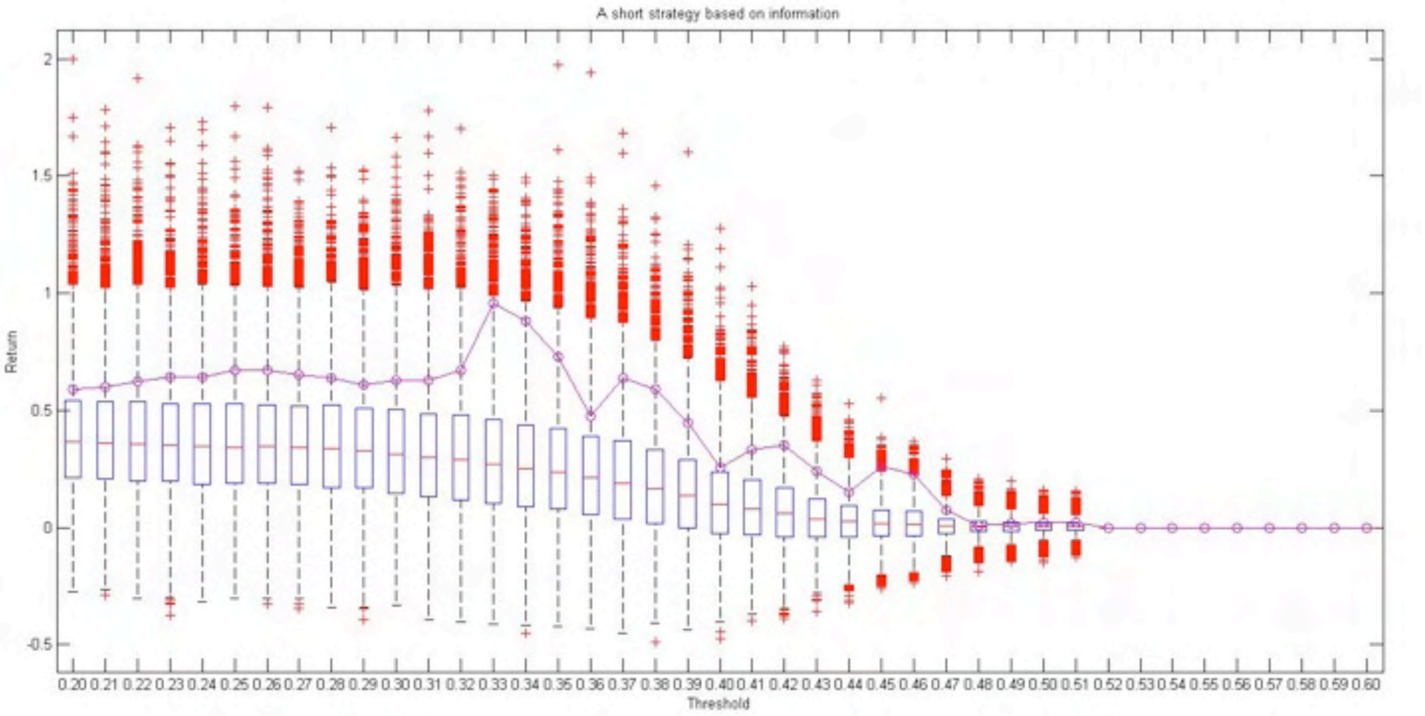


minority games
majority games
delayed minority games
delayed majority games
mixtures

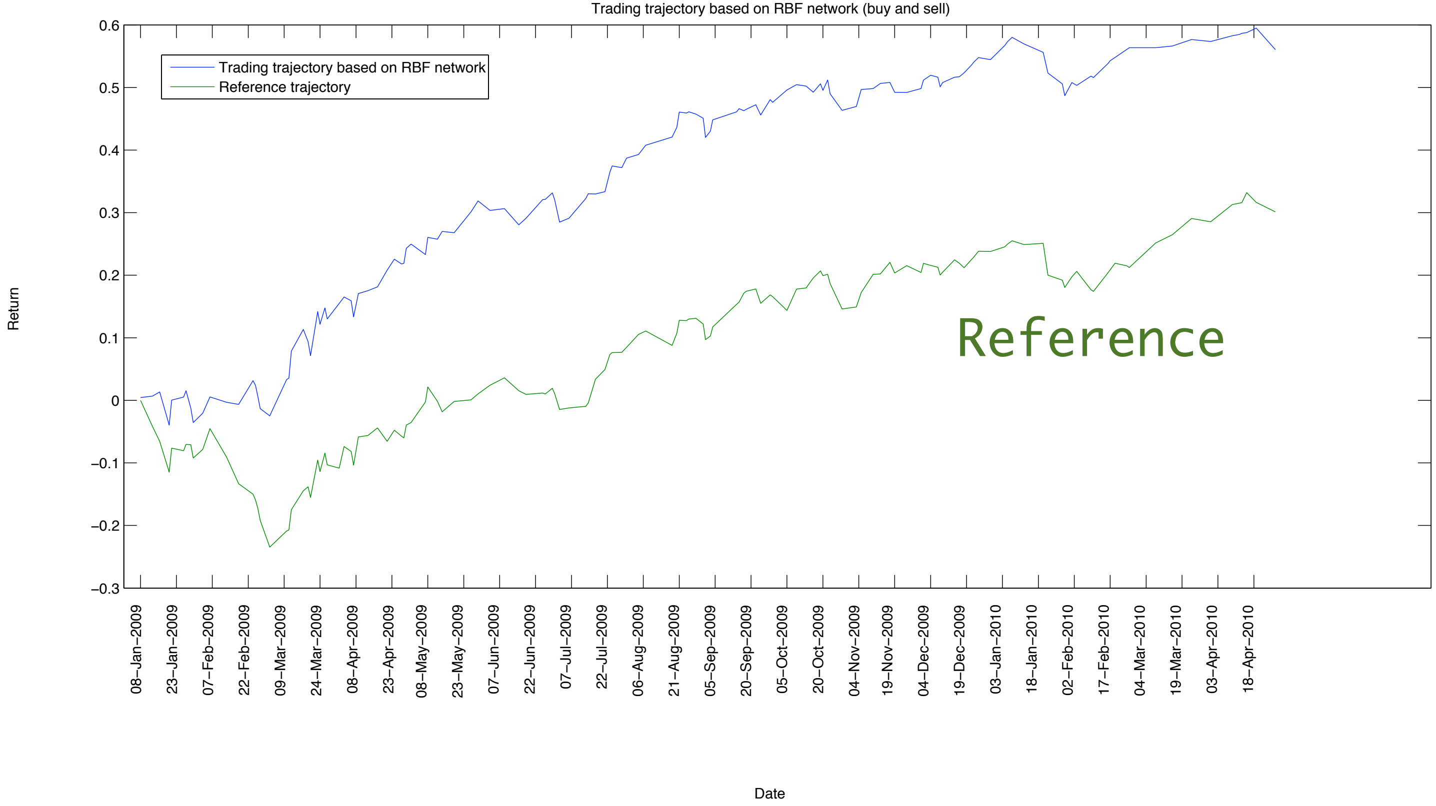
Semantic Language coding of news and Neural Networks

Q. Zhang and D. Sornette

- Collecting news stories from Internet
  - Websites of different sources such as NY Times, Reuters, etc
  - Yahoo Finance
  - Google
- Extracting information from News stories
- The preliminary results show some interesting relationships between information and stock prices. The following figure shows a short strategy based on information outperforms random trading on S&P500 index.



ANN trading based on news



- Demonstration of systemic relationships between news and S&P500 index.
- Negative news predicts better during recession.
- ANN trading based on news generates good results.
- Volatility has some linear relationship with negative news.

Out-of-equilibrium nonlinear financial economics

- Financial bubble experiments at ETH Zurich
- Reverse engineering of financial markets with agent-based models
- **Illusion of control**
- Multifractal endogenous econometric models for augmented variance estimators and forecasting
- Time-dependent lead-lag in econometrics
- Quantum decision theory

The Illusion of control

in Minority and Parrondo games

J. Satinover and D. Sornette

✓Individuals appear hard-wired to over-attribute success to skill, and to underestimate the role of chance, when both are in fact present.

[Langer, E. J., The Illusion of Control, Journal of Personality and Social Psychology 32 (2), 311-328 (1975)]

Overview: THMG

A. Time-Horizon MG (THMG): Pro/Con

B. In general, agents underperform strategies for "reasonable" **t** (no impact)

C. Agent performance declines with Hamming distance d_H between their strategies

D. Agent evolution: $d_H \rightarrow 0$

E. "Counteradaptive" agents perform best

J.B. Satinover and D. Sornette,
"Illusion of Control" in Minority and Parrondo Games,
Eur. Phys. J. B 60, 369-384 (2007)

Overview: Parrondo Games

A. 1^0 effect: two losing games win if alternated
B. History-dependent games
C. Attempt to optimize this effect inverts it
D. Shown in unusual multi-player setting
E. Here in natural single-player setting

J.B. Satinover and D. Sornette, Illusion of Control in a Brownian Game, Physica A 386, 339-344 (2007)

Overview: Other

A. Control in the MAJG and $G
B. Persistence/Anti-persistence in TH games
C. Cycle decomposition of TH games
D. Cycle predictor for real-world 1D series

J.B. Satinover and D. Sornette, Illusory versus Genuine Control in Agent-Based Games, Eur. Phys. J. B 67, 357-367 (2009)

J.B. Satinover and D. Sornette, Cycles, determinism and persistence in agent-based games and financial time-series, Quantitative Finance (in press) (http://arXiv.org/abs/0805.0428)

The illusion of control: Minority game

A strategy that has performed well in the past becomes crowded out in the future due the minority mechanism.

Optimizing agents tend on average to adapt to the past but not the present. They choose an action a(t) which is on average out-of-phase with the collective action A(t).

In contrast, non-optimizing agents average over all the regimes for which their strategy may be good and bad, and do not face the crowding-out effect.

The crowding-out effect also explains simply why anti-optimizing agents over-perform: choosing their worst strategy ensures that it will be the least used by other agents in the next time step, which implies that they will be in the minority.

Out-of-equilibrium nonlinear financial economics

- Financial bubble experiments at ETH Zurich

- Reverse engineering of financial markets with agent-based models

- Illusion of control

- **Multifractal endogenous econometric models for augmented variance estimators and forecasting**

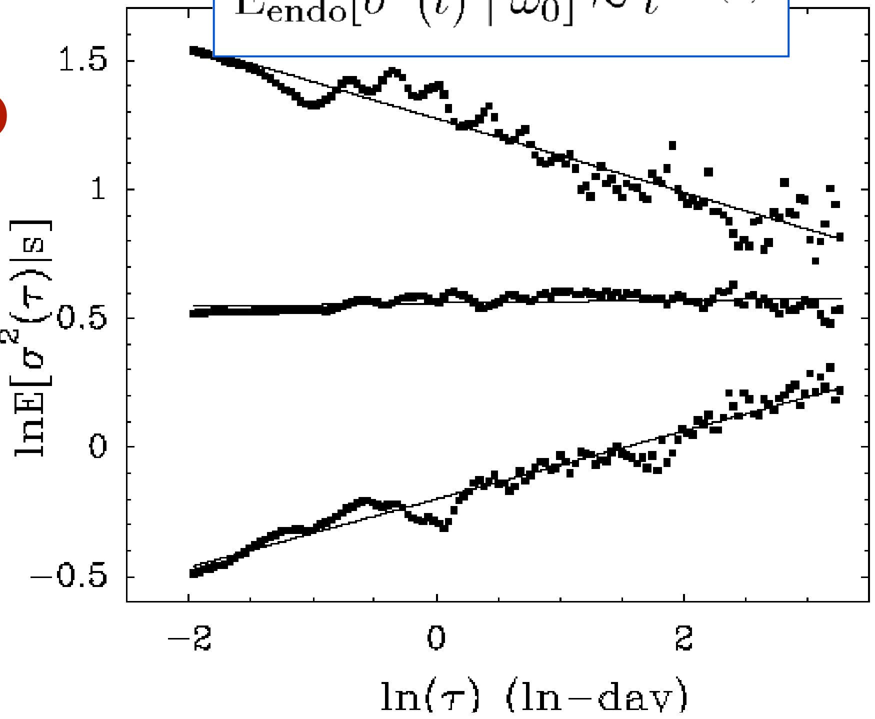
- Time-dependent lead-lag in econometrics

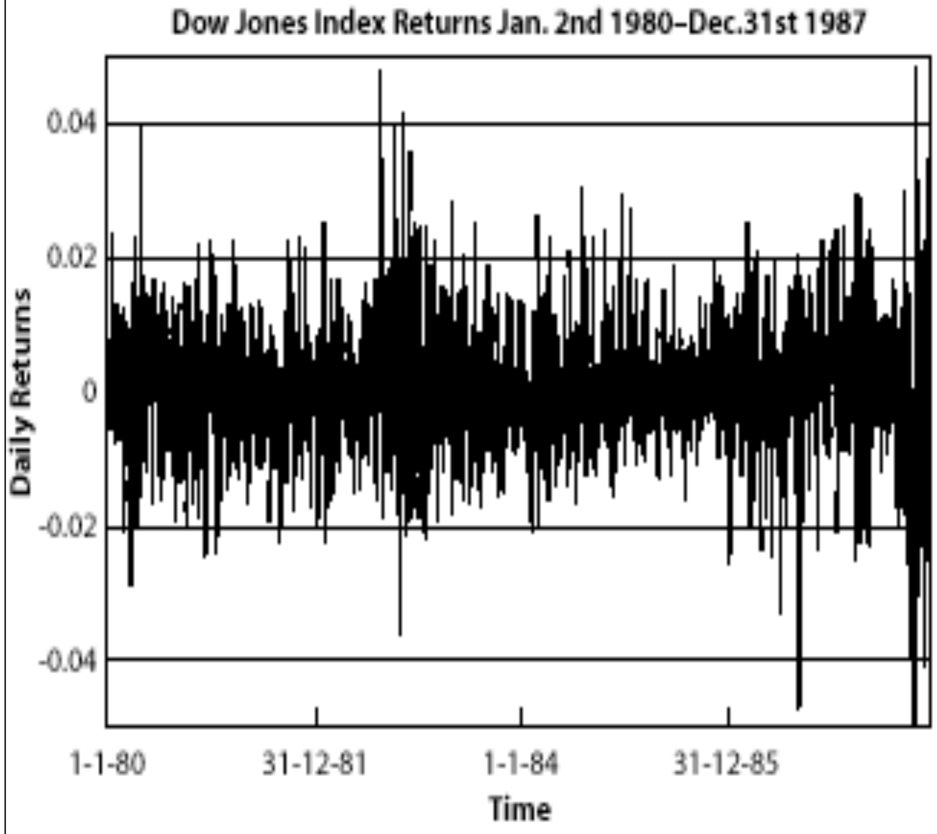
- Quantum decision theory

Financial volatility foreshocks and aftershocks

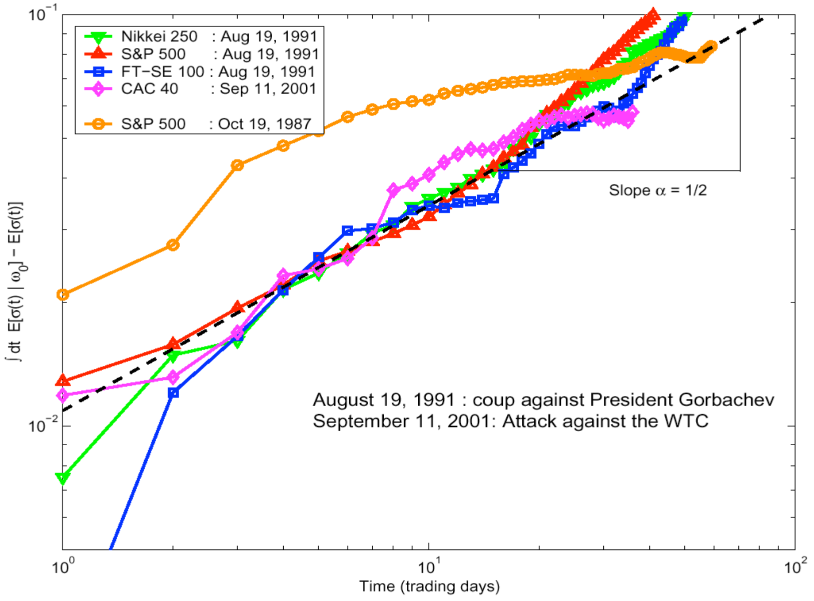
ENDO

$$\mathrm{E}_{\mathrm{endo}}[\sigma^2(t) \mid \omega_0] \sim t^{-\alpha(s)}$$





EXO



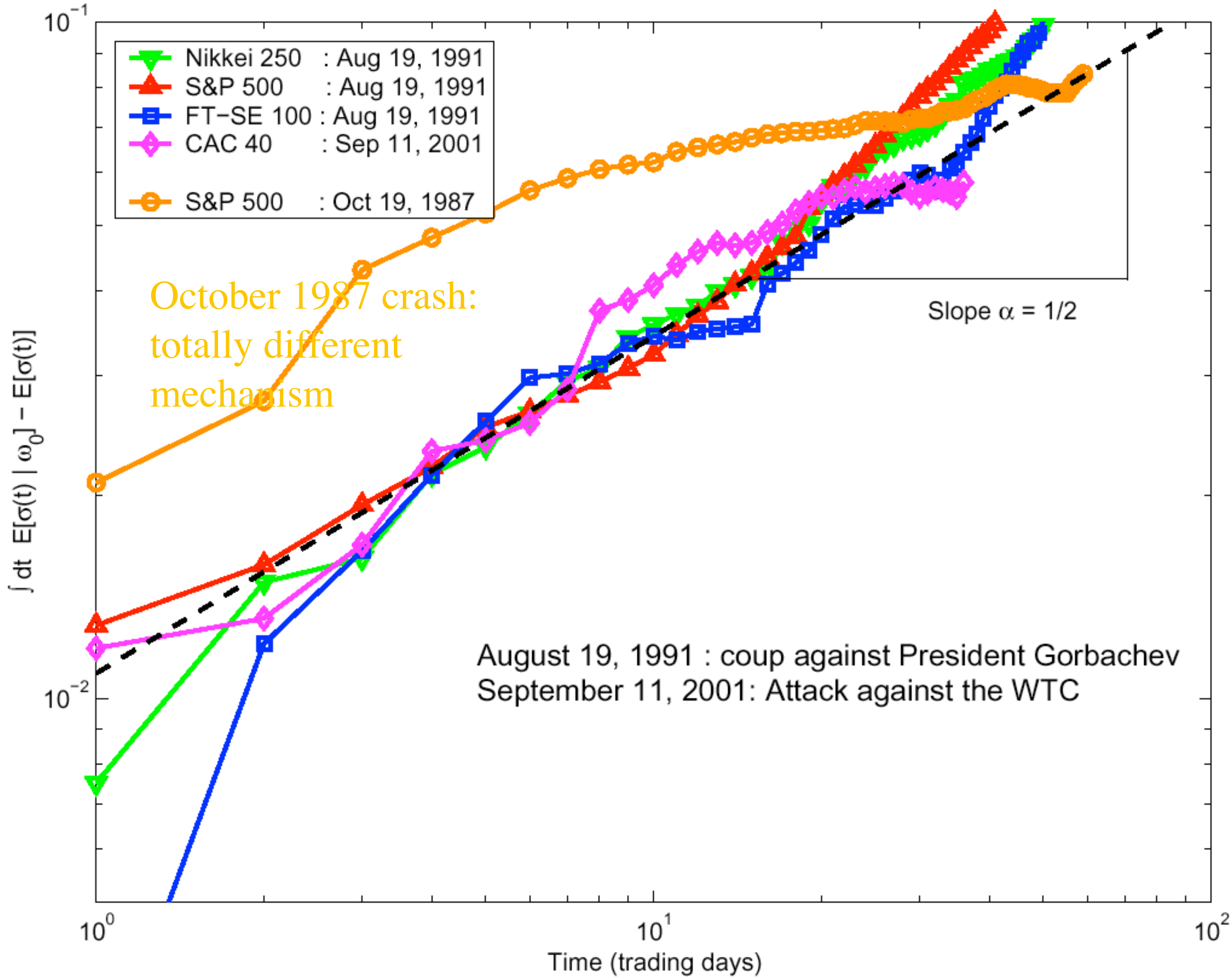
August 19, 1991 : coup against President Gorbachev
September 11, 2001: Attack against the WTC

$$\mathrm{E}_{\mathrm{exo}}[\sigma^2(t) \mid \omega_0] - \overline{\sigma^2(t)} \propto e^{2K_0 t^{-1/2}} - 1 \approx \frac{2K_0}{\sqrt{t}}$$

Linear response to an external shock

(Multifractal Random Walk model)

$$\mathrm{E}_{\mathrm{exo}}[\sigma^2(t) \mid \omega_0] - \overline{\sigma^2(t)} \propto e^{2K_0 t^{-1/2}} - 1 \approx \frac{2K_0}{\sqrt{t}}$$

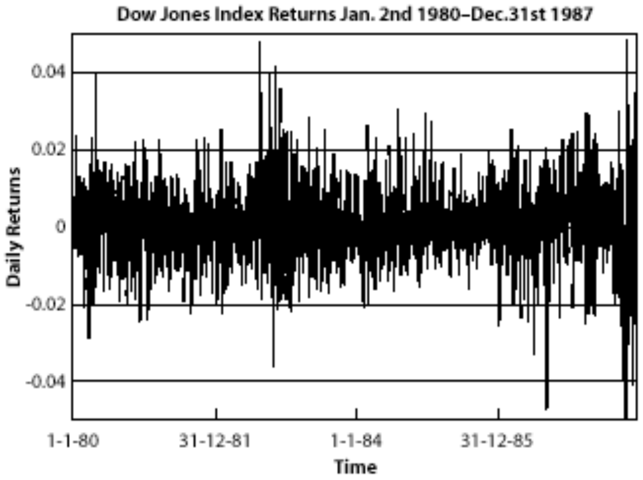


October 1987 crash: totally different mechanism

August 19, 1991 : coup against President Gorbachev
September 11, 2001: Attack against the WTC

D. Sornette, Y. Malevergne and J.F. Muzy Volatility fingerprints of large shocks: Endogeneous versus exogeneous, Risk Magazine (http://arXiv.org/abs/cond-mat/0204626)

“Conditional response” to an endogeneous shock



Interplay between
-long memory
-exponential

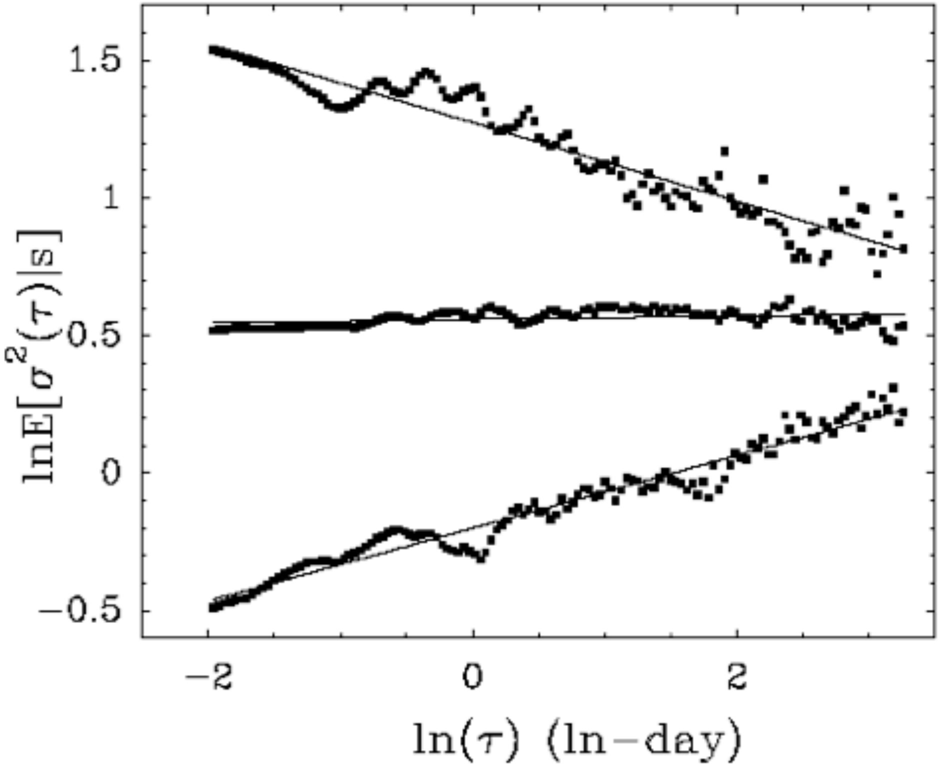
$$\boxed{\mathrm{E}_{\mathrm{endo}}[\sigma^2(t) \mid \omega_0] \sim t^{-\alpha(s)}}$$

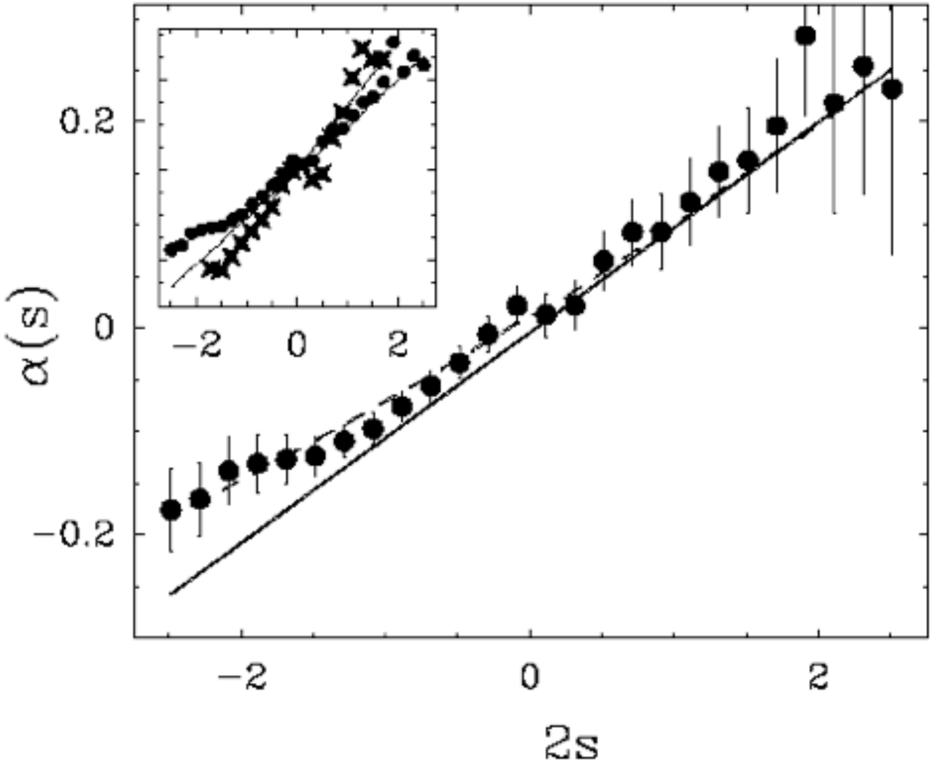
where $\alpha(s) = \dfrac{2s}{\ln\left(\frac{Te^{3/2}}{\Delta t}\right)}$

D. Sornette, Y. Malevergne and J.F. Muzy, Volatility fingerprints of large shocks: Endogeneous versus exogeneous, Risk 16 (2), 67-71 (2003) (http://arXiv.org/abs/cond-mat/0204626)

Real Data and Multifractal Random Walk model

$$\boxed{\mathrm{E}_{\mathrm{endo}}[\sigma^2(t) \mid \omega_0] \sim t^{-\alpha(s)}}$$





USING AGENT-BASED MODELS

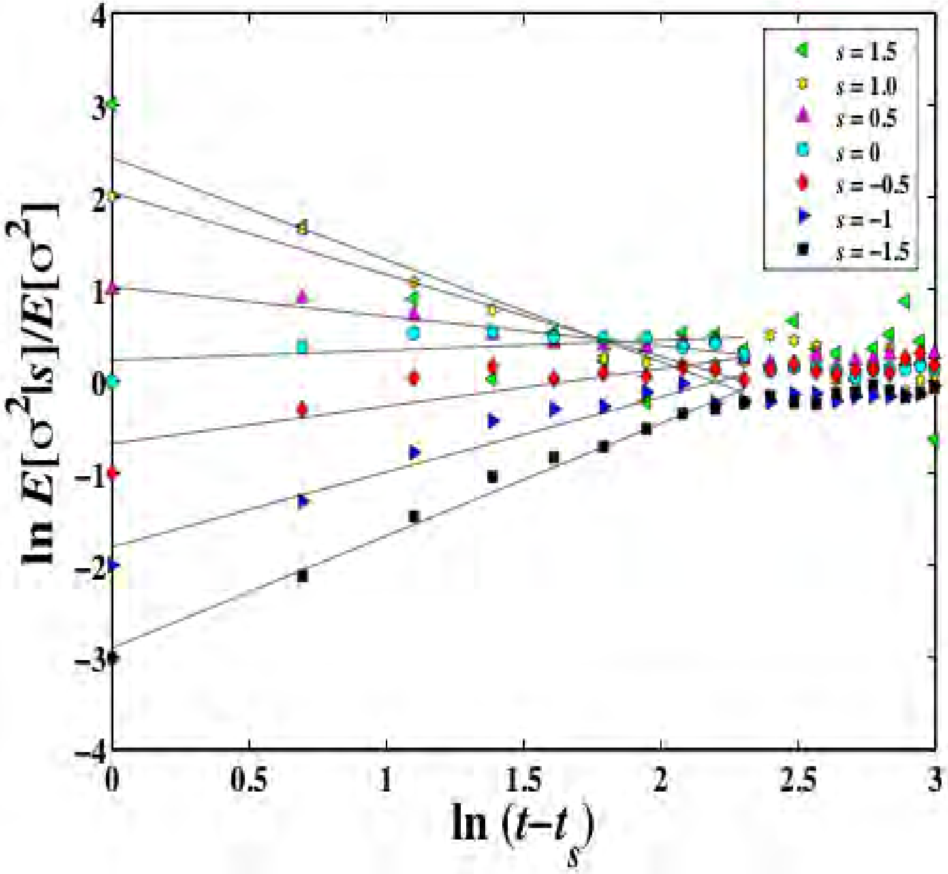


Fig. 12. Average normalized conditional volatility $\sigma^2_{\Delta t}(t)/E[\sigma^2]$ as a function of the time $t - t_s$ from the local burst of volatility at time t_s for different log-amplitudes s in double logarithmic coordinates.

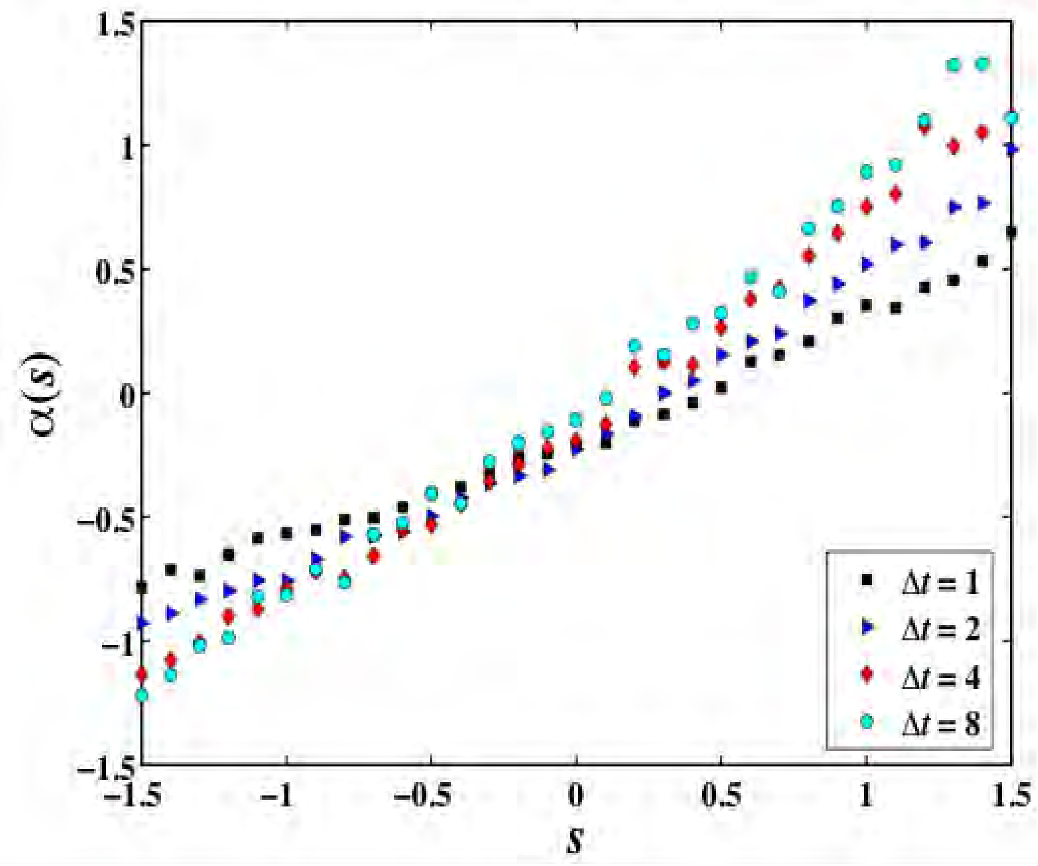
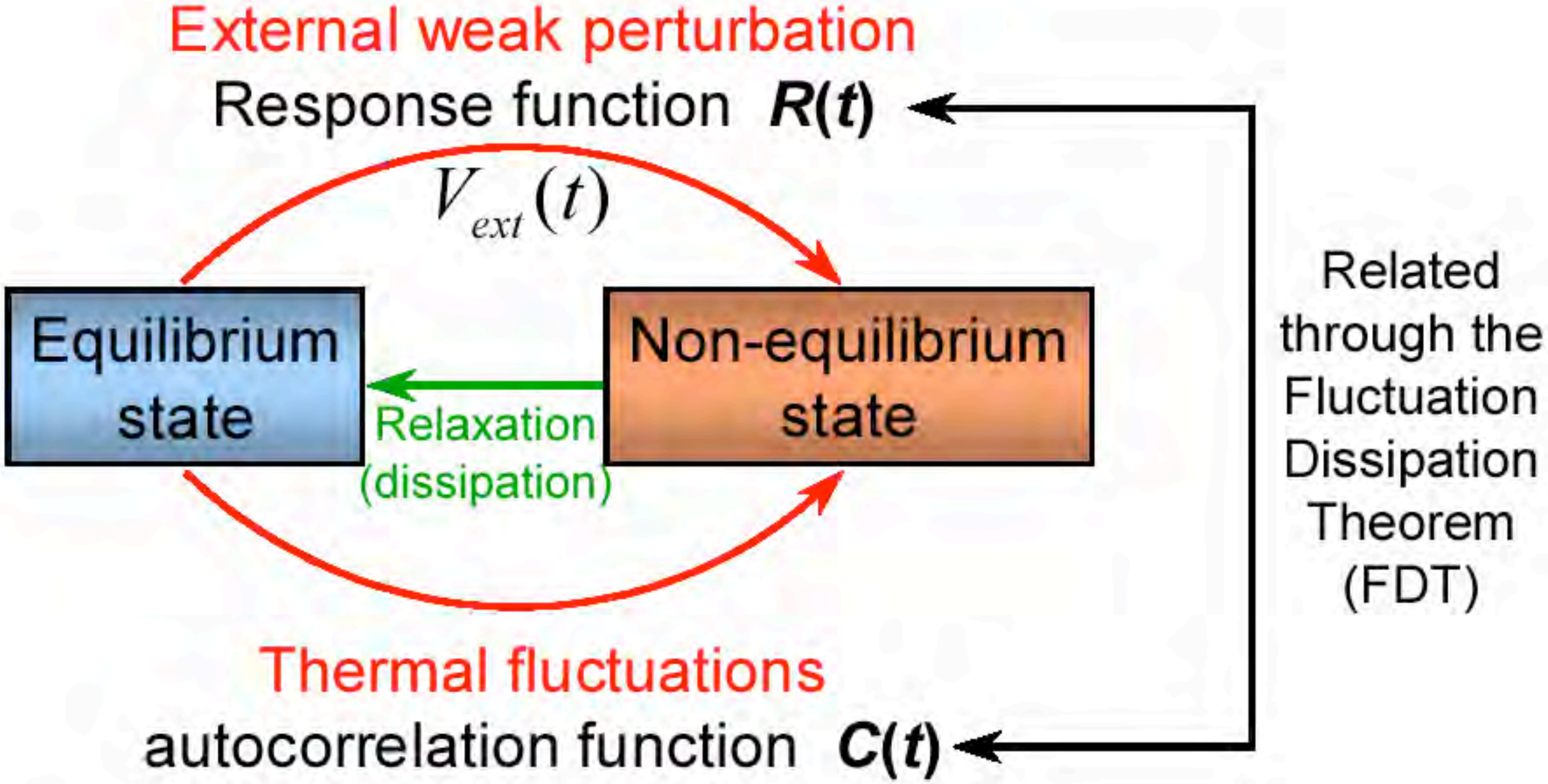


Fig. 13. Exponent $\alpha(s)$ of the conditional volatility response as a function of the endogenous shock amplitude S for $\Delta t = 1, 2, 4,$ and 8.

Didier Sornette and Wei-Xing Zhou, Importance of Positive Feedbacks and Over-confidence in a Self-Fulfilling Ising Model of Financial Markets, Physica A 370 (2), 704-726 (2006)

Response Theory



External weak perturbation

Response function **$R(t)$**

$V_{ext}(t)$

Equilibrium state

Non-equilibrium state

Relaxation (dissipation)

Thermal fluctuations

autocorrelation function **$C(t)$**

Related through the Fluctuation Dissipation Theorem (FDT)

Endogenous versus Exogenous

Extinctions

- -meteorite at the Cretaceous/Tertiary KT boundary
- -volcanic eruptions (Deccan traps)
- -self-organized critical events

Discoveries

- -serendipity
- -maturation

Volatility bursts in financial time series

- -external shock
- -cumulative effect of "small" news

Financial crashes

- -external shock
- -self-organized instability

Earthquakes

- -tectonic driving
- -triggering

Immune system

- -external viral or bacterial attack
- - " internal" (dis-)organization

Parturition

- -mother/foetus triggered?
- -mother-foetus complex?

Brain (learning)

- -external inputs
- -internal self-organization and reinforcements (role of sleep)

Aviation industry recession

- -September 11, 2001
- -structural endogenous problems

Commercial success and sales

- -Ads
- -epidemic network

Recovery after wars?

- -internally generated (civil wars)
- -externally generated

Social unrests

- -triggering factors
- -rotting of social tissue

Forecasting historical and implied volatility with the MRW

J.-F. Muzy and D. Sornette

Wiener filtering: $\tilde{Y} = \sum^{N} \alpha_i Z_i$

Wiener filter weights: $\alpha_i = \sum_{k=1}^{N} S_{k,i}^{-1} R_k$

minimize mean square $E((\tilde{Y} - Y)^2)$

$S_{k,l}$ is the correlation matrix $E(Z_k Z_l)$

R_k is the correlation function $E(Y Z_k)$

The Wiener filter corresponds to the maximum likelihood forecasting in the case of (jointly)-Gaussian random variables (Y,Z).

Forecasting historical and implied volatility with the MRW

Log-squared return forecasting (`MRWlog` method)

MRW: $r_l(t) \equiv \Sigma_l(t)\epsilon(t)$

$$\mu_l = \frac{1}{2}\left(\ln(\sigma^2 l) + 2\lambda^2 \ln(\frac{l}{L'})\right)$$

$$V_l = -\lambda^2 \ln(\frac{l}{L'})$$

are mean and variance of $\ln \Sigma_l$

$$\mathrm{Cov}_l(\tau) = \begin{cases} \lambda^2 \ln(\frac{L'}{l}) - \lambda^2 (\frac{\tau}{l})^2 \ln(\frac{e^{3/2} l}{\tau}) & \text{if } |\tau| \leq l \\ \lambda^2 \ln(\frac{L}{\tau}) & \text{if } L \geq |\tau| \geq l \\ 0 & \text{otherwise} \end{cases}$$

log-normal approximation for $\Sigma_l(t)$

Wiener filter based on these three variables above

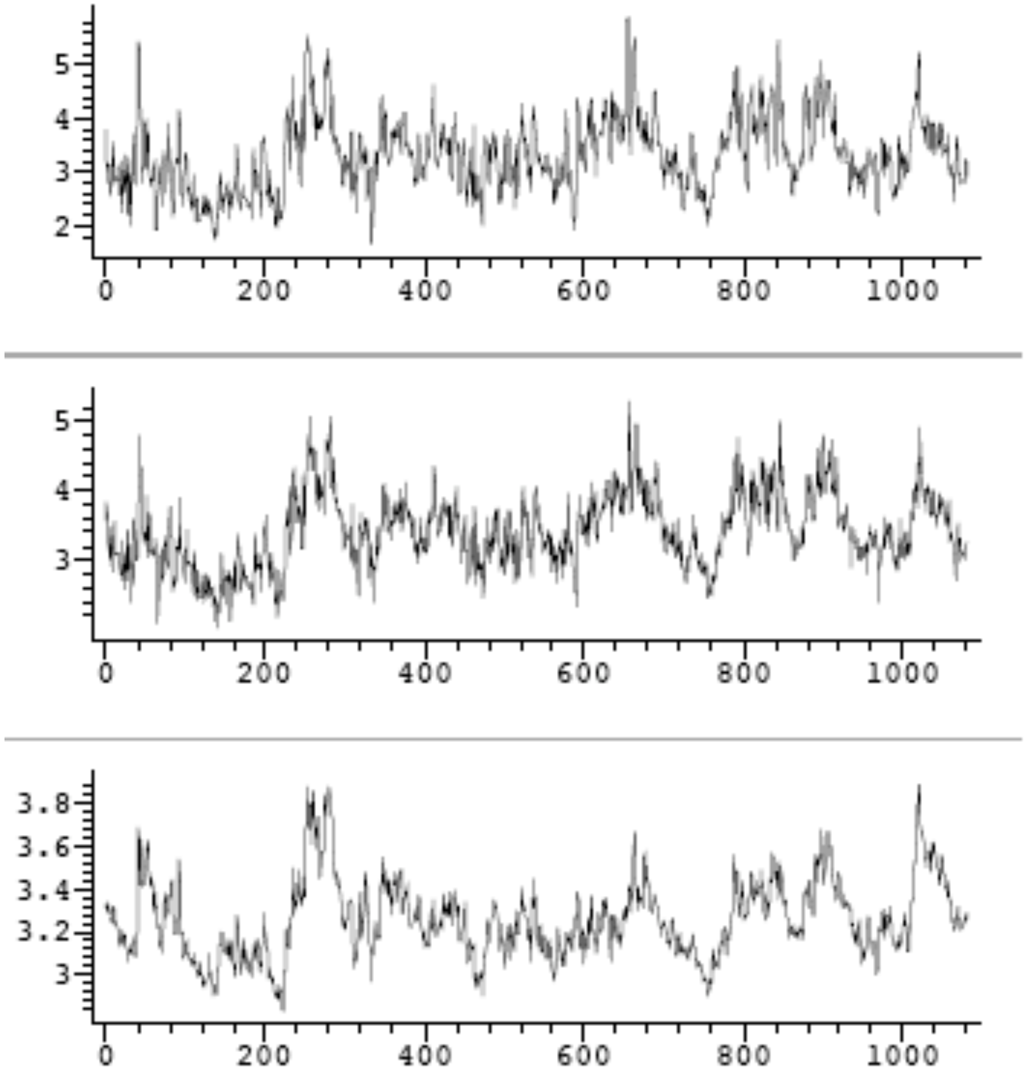
$$y_l = \frac{1}{2}\ln(r_l^2)$$

$$Z_1 = \tfrac{1}{2}\ln(r_l(t)^2),\ldots,Z_{k+1} = \tfrac{1}{2}\ln(r_l(t-kl)^2)$$

$$Y = \Sigma_l^2(t+pl)$$

$$\tilde{Y}(t+pl) = e^{2\tilde{y}(t+pl)+2\kappa e_y}$$

For larger coarser-scales: $\tilde{Y} = \sum_{j=0}^{m-1} \tilde{Y}(t+(p-j)l)$



S&P100 daily
historical vol

MRWlog vol
1d forecast

Log-VIX
implied vol index

Figure 2: From top to bottom: S&P 100 logarithm of daily historical volatility, MRWlog log- daily volatility one day ahead forecast, logarithm of VIX implied volatility index

R2 value/scale	Risk Metrics	Garch(1,1)	MRWlinc	MRWlog (intraday vol)
30 days	0.34	0.52	0.44	**0.61**

Table 1: Comparison of R2 values for different historical forecasts

Forecasting historical and implied volatility with the MRW

$horizon = 1, 10, 20, 120$ days and $scale = 1, 10, 20, 120$ days,

1 day, 10 days, one month and six months future volatilities

Comparison with RiskMetrics and Garch(1,1)

$$\boxed{100 \times (RMSE_{RiskMetrics} - RMSE)/RMSE_{RiskMetrics})}$$

SP 500 index : 28/12/61 – 25/04/00

s = 1 day, h = …	Historic	Garch(1,1)	MRWlin	MRWlog
RMSE 10 days	+37.41	-0.09	-1.67	**-1.97**
1 month	+37.65	-0.66	-1.92	**-2.06**
6 months	+37.17	**-2.57**	-2.42	-2.35
MAE 10 days	+20.38	-4.24	-10.60	**-22.83**
1 month	+20.92	-6.80	-12.82	**-23.96**
6 months	+18.35	-17.42	-19.09	**-26.25**

MAE: Mean Absolute Error

Intraday forecasting based on intraday returns

Nasdaq composite index : 04/08/97 – 18/3/02 (96430/45107) (intraday 5m)

Error/scale	Historic	Garch(1,1)	MRWlinc	MRWlog
RMSE 10min	-1.12	-13.38	-13.70	**-21.78**
30 min	-14.56	-17.66	-18.93	**-28.44**
1 hour	-8.32	-17.18	-21.21	**-32.93**
MAE 10 min	+11.18	-8.02	-4.78	**-17.39**
30 min	-2.25	-11.22	-7.69	**-21.28**
1 hour	+0.28	-12.63	-9.83	**-25.43**

Error/horizon (30m)	Historic	Garch(1,1)	MRWlinc	MRWlog
RMSE 30 min	-14.82	-19.30	-23.27	**-35.40**
1 hour	-2.18	-18.85	-29.30	**-42.83**
1 day	-12.54	-27.52	-24.96	**-29.34**
MAE 30 min	+0.92	-12.03	-9.32	**-25.25**
1 hour	+9.32	-12.90	-11.41	**-28.61**
1 day	-0.37	-24.11	-13.58	**-26.65**

Out-of-equilibrium nonlinear financial economics

- Financial bubble experiments at ETH Zurich

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- Illusion of control

- Multifractal endogenous econometric models for augmented variance estimators and forecasting

- **Time-dependent lead-lag in econometrics**

- Quantum decision theory

The US stock market leads the Federal funds rate and Treasury bond yields

(Non-parametric Determination of Real-Time Lag Structure by the TOP method)

“SLAVING OF THE FED TO THE STOCK MARKET”

Kun Guo [1], Wei-Xing Zhou [1,2,3,4], Si-Wei Cheng [3], Didier Sornette [5,6]

1 Research Center on Fictitious Economy and Data Science, Chinese Academy of Sciences, Beijing, China

2 School of Business, East China University of Science and Technology, Shanghai

3 School of Science, East China University of Science and Technology, Shanghai

4 Research Center for Econophysics, East China University of Science and Technology, Shanghai, China

5 Department of Management, Technology and Economics, ETH Zurich, Zurich, Switzerland

6 Swiss Finance Institute, c/o University of Geneva, Geneva, Switzerland

Adaptive lead-lag dependence and applications

Didier Sornette and Wei-Xing Zhou
Non-parametric Determination of Real-Time Lag Structure between Two Time Series: the ``Optimal Thermal Causal Path'' Method,
Quantitative Finance 5 (6), 577-591 (2005)
(http://arXiv.org/abs/cond-mat/0408166)

Wei-Xing Zhou and Didier Sornette
Non-parametric Determination of Real-Time Lag Structure between Two Time Series: the ``Optimal Thermal Causal Path'' Method with Applications to Economic Data, Journal of Macroeconomics, 28, 195-224 (2006)

Wei-Xing Zhou and Didier Sornette
Lead-lag cross-sectional structure and detection of correlated-anticorrelated regime shifts: application to the volatilities of inflation and economic growth rates,
Physica A 380, 287–296 (2007)
(http://arxiv.org/abs/physics/0607197)

Wei-Xing Zhou and Didier Sornette
Causal Slaving of the U.S. Treasury Bond Yield Antibubble by the Stock Market Antibubble of August 2000, Physica A 337, 586-608 (2004)
(http://arXiv.org/abs/cond-mat/0312658)

Guo-Hua Mu, Wei-Xing Zhou, Wei Chen and Didier Sornette
Strategies used as Spectroscopy of Financial Markets Reveal New Stylized Facts,
PLoS ONE 6 (9), 1-9 (e24391) (2011)
(http://arxiv.org/abs/1104.3616)

Optimal Thermal Causality Path

1) two time series

2) Standardize them (remove mean and normalize by std)

$$\{X(t_1) : t_1 = 0, ...n\} \text{ and } \{Y(t_2) : t_2 = 0, ...n\}$$

3) Define distance matrix (different norms are possible)

$$\epsilon(t_1, t_2) = |X(t_1) - Y(t_1)|$$

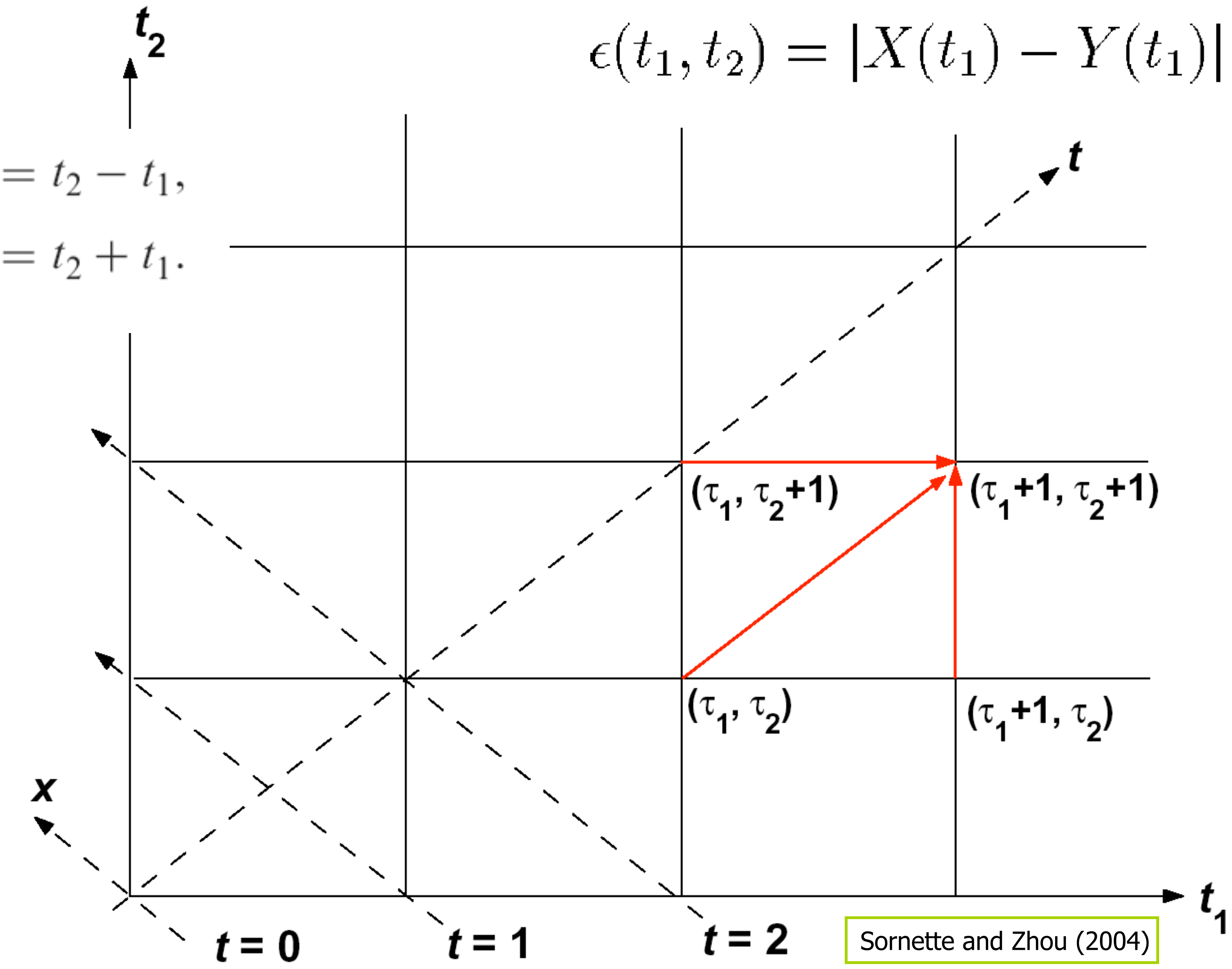
Sornette and Zhou (2004)

Optimal Thermal Causality Path

$$\{X(t_1) : t_1 = 0, ...n\} \text{ and } \{Y(t_2) : t_2 = 0, ...n\}$$

$$\epsilon(t_1, t_2) = |X(t_1) - Y(t_1)|$$

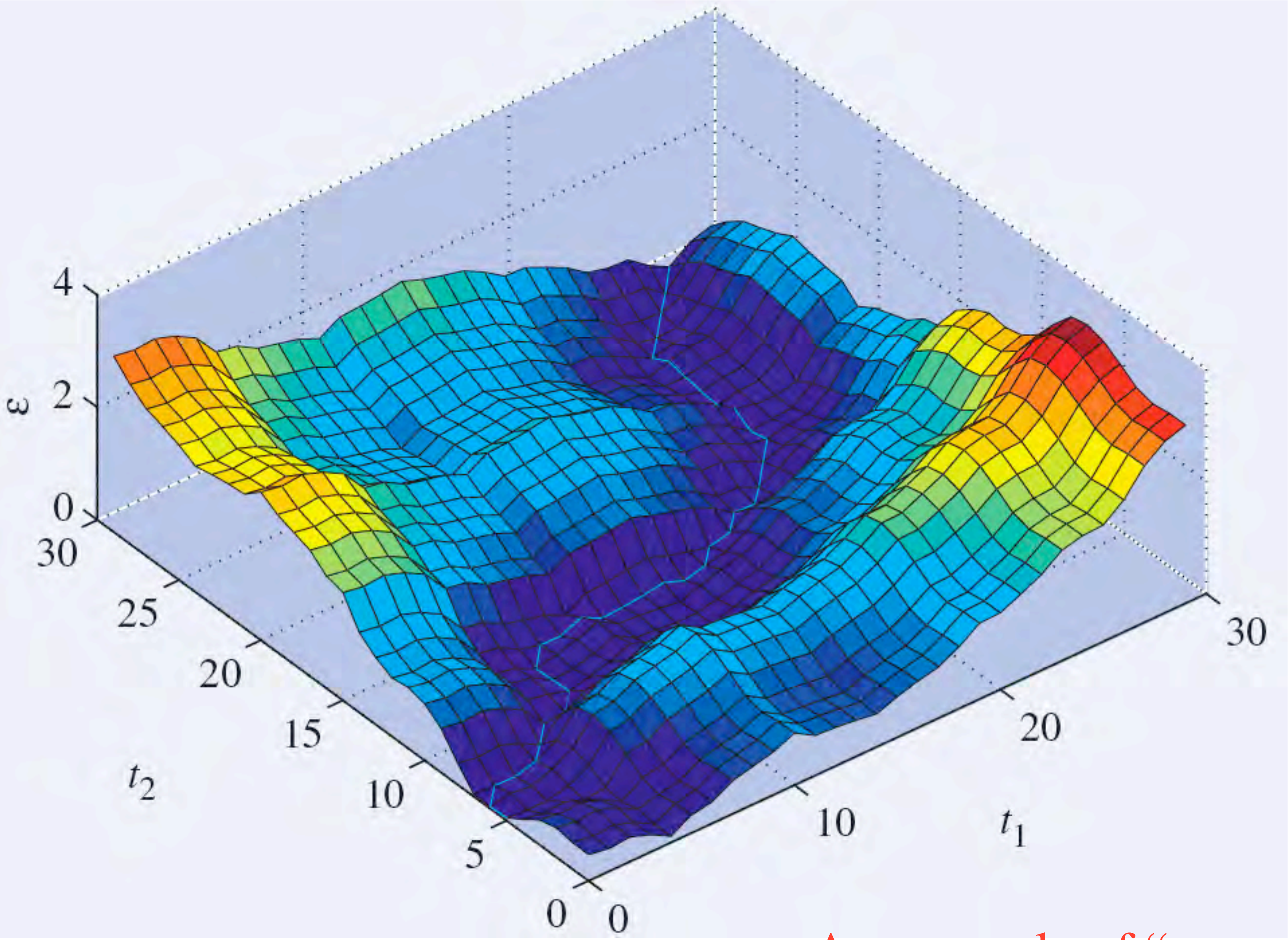
$$\begin{cases} x = t_2 - t_1, \\ t \ = t_2 + t_1. \end{cases}$$



Sornette and Zhou (2004)

distance matrix $E_{X,Y}$ between X to Y

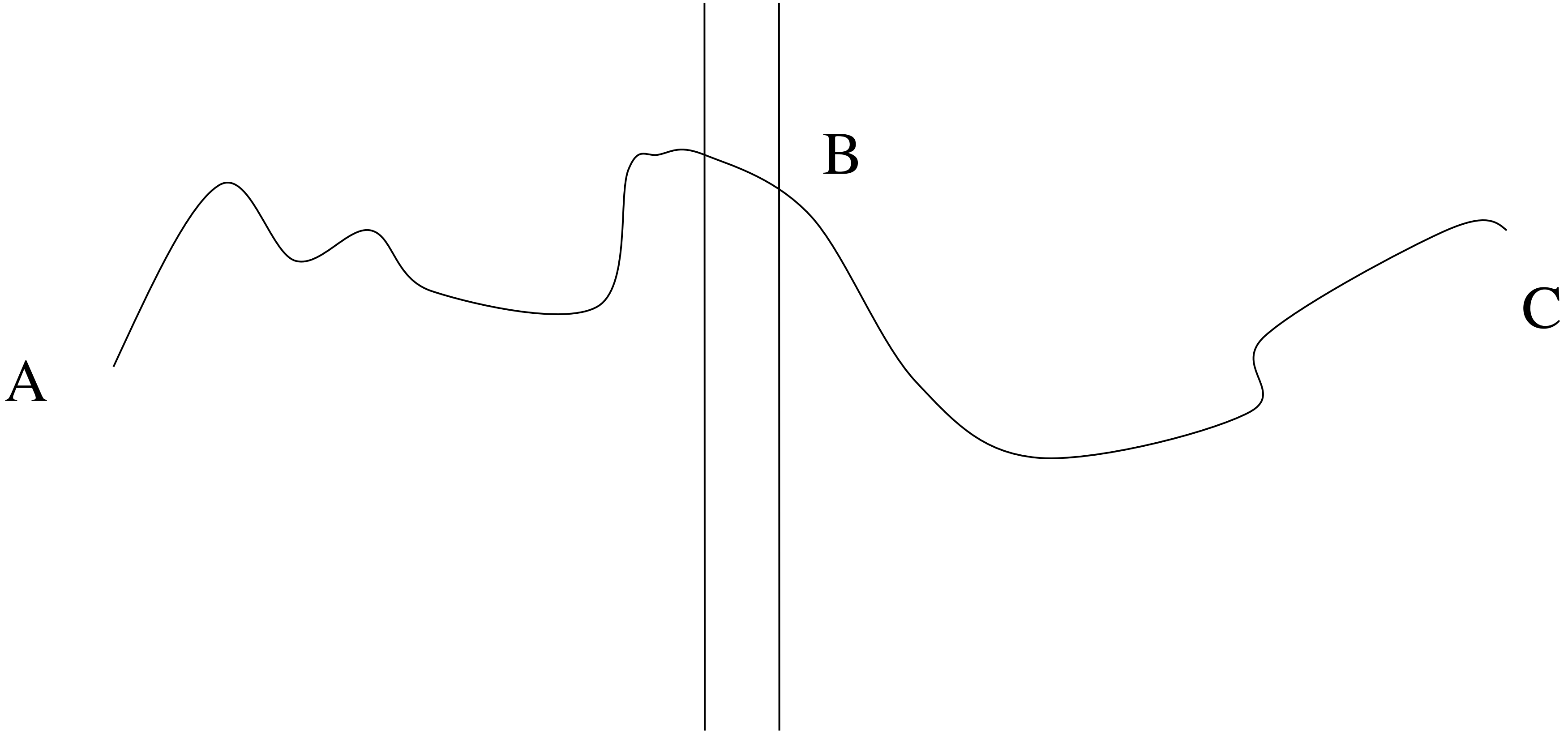
$$\epsilon(t_1, t_2) = |X(t_1) - Y(t_2)|.$$

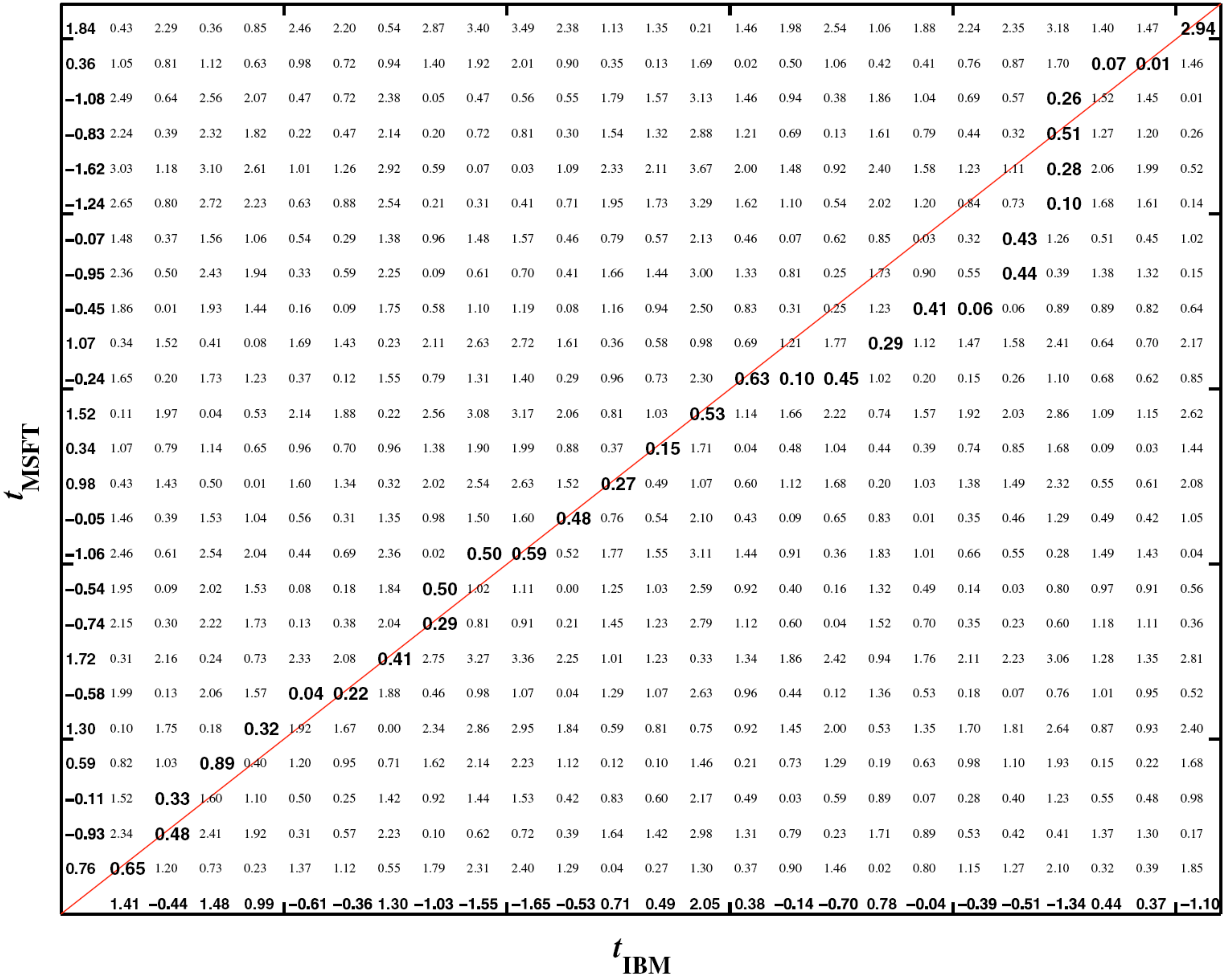


An example of “energy” landscape

The transfer matrix method is based on the following fundamental relation:

$$E(t_1, t_2) = \epsilon(t_1, t_2) + \mathrm{Min}[E(t_1 - 1, t_2), E(t_1, t_2 - 1), E(t_1 - 1, t_2 - 1)].$$





1.84	0.43	2.29	0.36	0.85	2.46	2.20	0.54	2.87	3.40	3.49	2.38	1.13	1.35	0.21	1.46	1.98	2.54	1.06	1.88	2.24	2.35	3.18	1.40	1.47	**2.94**
0.36	1.05	0.81	1.12	0.63	0.98	0.72	0.94	1.40	1.92	2.01	0.90	0.35	0.13	1.69	0.02	0.50	1.06	0.42	0.41	0.76	0.87	1.70	**0.07**	**0.01**	1.46
–1.08	2.49	0.64	2.56	2.07	0.47	0.72	2.38	0.05	0.47	0.56	0.55	1.79	1.57	3.13	1.46	0.94	0.38	1.86	1.04	0.69	0.57	**0.26**	1.52	1.45	0.01
–0.83	2.24	0.39	2.32	1.82	0.22	0.47	2.14	0.20	0.72	0.81	0.30	1.54	1.32	2.88	1.21	0.69	0.13	1.61	0.79	0.44	0.32	**0.51**	1.27	1.20	0.26
–1.62	3.03	1.18	3.10	2.61	1.01	1.26	2.92	0.59	0.07	0.03	1.09	2.33	2.11	3.67	2.00	1.48	0.92	2.40	1.58	1.23	1.11	**0.28**	2.06	1.99	0.52
–1.24	2.65	0.80	2.72	2.23	0.63	0.88	2.54	0.21	0.31	0.41	0.71	1.95	1.73	3.29	1.62	1.10	0.54	2.02	1.20	0.84	0.73	**0.10**	1.68	1.61	0.14
–0.07	1.48	0.37	1.56	1.06	0.54	0.29	1.38	0.96	1.48	1.57	0.46	0.79	0.57	2.13	0.46	0.07	0.62	0.85	0.03	0.32	**0.43**	1.26	0.51	0.45	1.02
–0.95	2.36	0.50	2.43	1.94	0.33	0.59	2.25	0.09	0.61	0.70	0.41	1.66	1.44	3.00	1.33	0.81	0.25	1.73	0.90	0.55	**0.44**	0.39	1.38	1.32	0.15
–0.45	1.86	0.01	1.93	1.44	0.16	0.09	1.75	0.58	1.10	1.19	0.08	1.16	0.94	2.50	0.83	0.31	0.25	1.23	**0.41**	**0.06**	0.06	0.89	0.89	0.82	0.64
1.07	0.34	1.52	0.41	0.08	1.69	1.43	0.23	2.11	2.63	2.72	1.61	0.36	0.58	0.98	0.69	1.21	1.77	**0.29**	1.12	1.47	1.58	2.41	0.64	0.70	2.17
–0.24	1.65	0.20	1.73	1.23	0.37	0.12	1.55	0.79	1.31	1.40	0.29	0.96	0.73	2.30	**0.63**	**0.10**	**0.45**	1.02	0.20	0.15	0.26	1.10	0.68	0.62	0.85
1.52	0.11	1.97	0.04	0.53	2.14	1.88	0.22	2.56	3.08	3.17	2.06	0.81	1.03	**0.53**	1.14	1.66	2.22	0.74	1.57	1.92	2.03	2.86	1.09	1.15	2.62
0.34	1.07	0.79	1.14	0.65	0.96	0.70	0.96	1.38	1.90	1.99	0.88	0.37	**0.15**	1.71	0.04	0.48	1.04	0.44	0.39	0.74	0.85	1.68	0.09	0.03	1.44
0.98	0.43	1.43	0.50	0.01	1.60	1.34	0.32	2.02	2.54	2.63	1.52	**0.27**	0.49	1.07	0.60	1.12	1.68	0.20	1.03	1.38	1.49	2.32	0.55	0.61	2.08
–0.05	1.46	0.39	1.53	1.04	0.56	0.31	1.35	0.98	1.50	1.60	**0.48**	0.76	0.54	2.10	0.43	0.09	0.65	0.83	0.01	0.35	0.46	1.29	0.49	0.42	1.05
–1.06	2.46	0.61	2.54	2.04	0.44	0.69	2.36	0.02	**0.50**	**0.59**	0.52	1.77	1.55	3.11	1.44	0.91	0.36	1.83	1.01	0.66	0.55	0.28	1.49	1.43	0.04
–0.54	1.95	0.09	2.02	1.53	0.08	0.18	1.84	**0.50**	1.02	1.11	0.00	1.25	1.03	2.59	0.92	0.40	0.16	1.32	0.49	0.14	0.03	0.80	0.97	0.91	0.56
–0.74	2.15	0.30	2.22	1.73	0.13	0.38	2.04	**0.29**	0.81	0.91	0.21	1.45	1.23	2.79	1.12	0.60	0.04	1.52	0.70	0.35	0.23	0.60	1.18	1.11	0.36
1.72	0.31	2.16	0.24	0.73	2.33	2.08	**0.41**	2.75	3.27	3.36	2.25	1.01	1.23	0.33	1.34	1.86	2.42	0.94	1.76	2.11	2.23	3.06	1.28	1.35	2.81
–0.58	1.99	0.13	2.06	1.57	**0.04**	**0.22**	1.88	0.46	0.98	1.07	0.04	1.29	1.07	2.63	0.96	0.44	0.12	1.36	0.53	0.18	0.07	0.76	1.01	0.95	0.52
1.30	0.10	1.75	0.18	**0.32**	1.92	1.67	0.00	2.34	2.86	2.95	1.84	0.59	0.81	0.75	0.92	1.45	2.00	0.53	1.35	1.70	1.81	2.64	0.87	0.93	2.40
0.59	0.82	1.03	**0.89**	0.40	1.20	0.95	0.71	1.62	2.14	2.23	1.12	0.12	0.10	1.46	0.21	0.73	1.29	0.19	0.63	0.98	1.10	1.93	0.15	0.22	1.68
–0.11	1.52	**0.33**	1.60	1.10	0.50	0.25	1.42	0.92	1.44	1.53	0.42	0.83	0.60	2.17	0.49	0.03	0.59	0.89	0.07	0.28	0.40	1.23	0.55	0.48	0.98
–0.93	2.34	**0.48**	2.41	1.92	0.31	0.57	2.23	0.10	0.62	0.72	0.39	1.64	1.42	2.98	1.31	0.79	0.23	1.71	0.89	0.53	0.42	0.41	1.37	1.30	0.17
0.76	**0.65**	1.20	0.73	0.23	1.37	1.12	0.55	1.79	2.31	2.40	1.29	0.04	0.27	1.30	0.37	0.90	1.46	0.02	0.80	1.15	1.27	2.10	0.32	0.39	1.85
	1.41	**–0.44**	**1.48**	**0.99**	**–0.61**	**–0.36**	**1.30**	**–1.03**	**–1.55**	**–1.65**	**–0.53**	**0.71**	**0.49**	**2.05**	**0.38**	**–0.14**	**–0.70**	**0.78**	**–0.04**	**–0.39**	**–0.51**	**–1.34**	**0.44**	**0.37**	**–1.10**

Fig. 6. Distance matrix of the normalized returns of IBM and MSFT stocks from 2001/05/16 to 2001/06/20. The normalized returns are in the first row (bottom) and first column (left). The corresponding distance matrix is with the optimal path in bold. The straight line characterizes the diagonal (no time lag).

Metastable states in random media

Random directed polymers

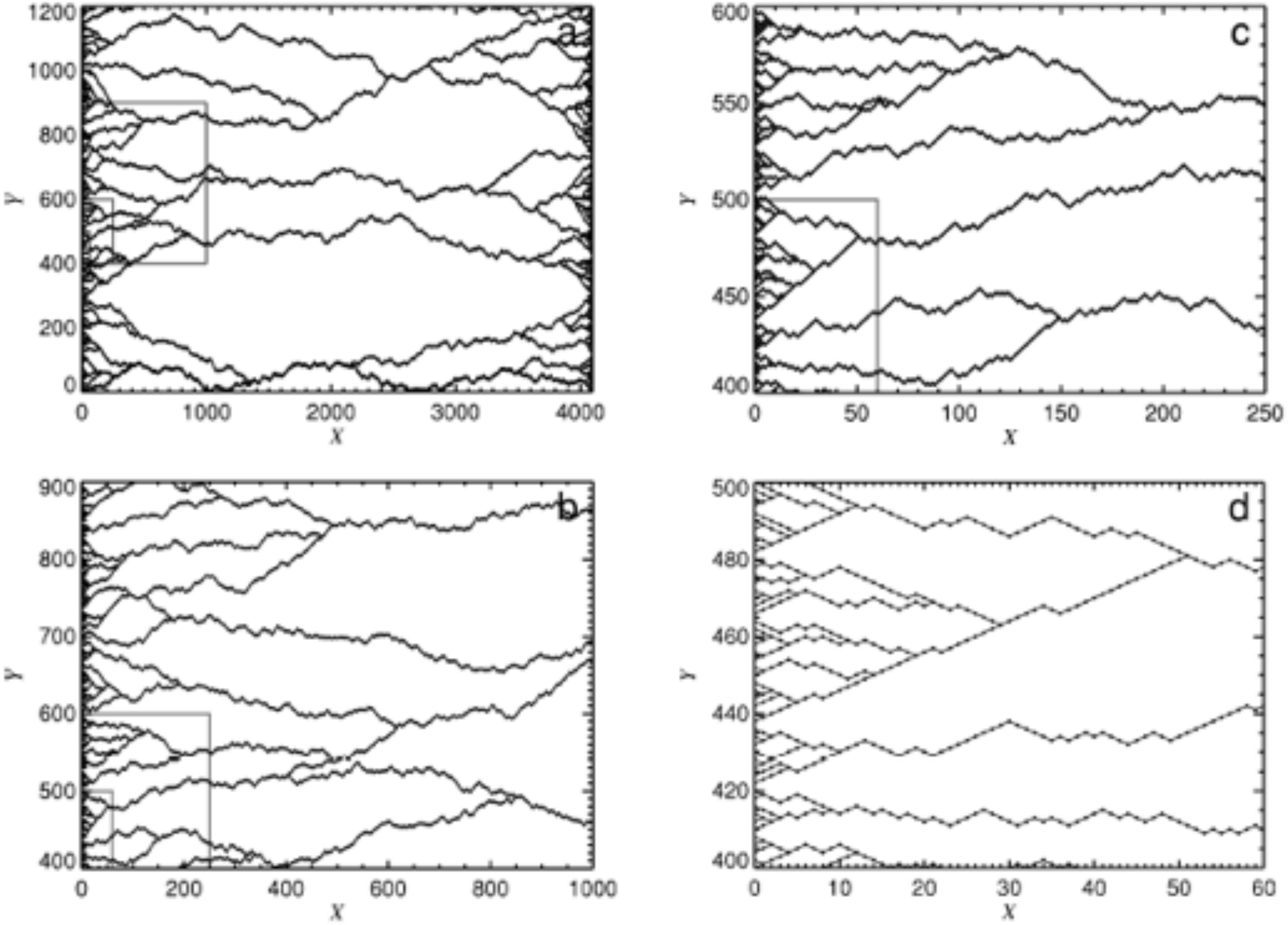


FIG. 1. Typical set of optimal configurations for a RDP of length $W=4096$ and for $0\leq y\leq 1200$: (a) global system [gray framed boxes outline regions of succeeding plots such that the horizontal and vertical extensions of these boxes follow Eqs. (10) and (8) with $\alpha\approx 0.9$], (b) magnification of the largest box in (a), (c) magnification of the largest box in (b) and (d) magnification of the box in (c). Note, that at each grid point of the lattice we assign an independent random number drawn from an exponential distribution with unit mean and variance.

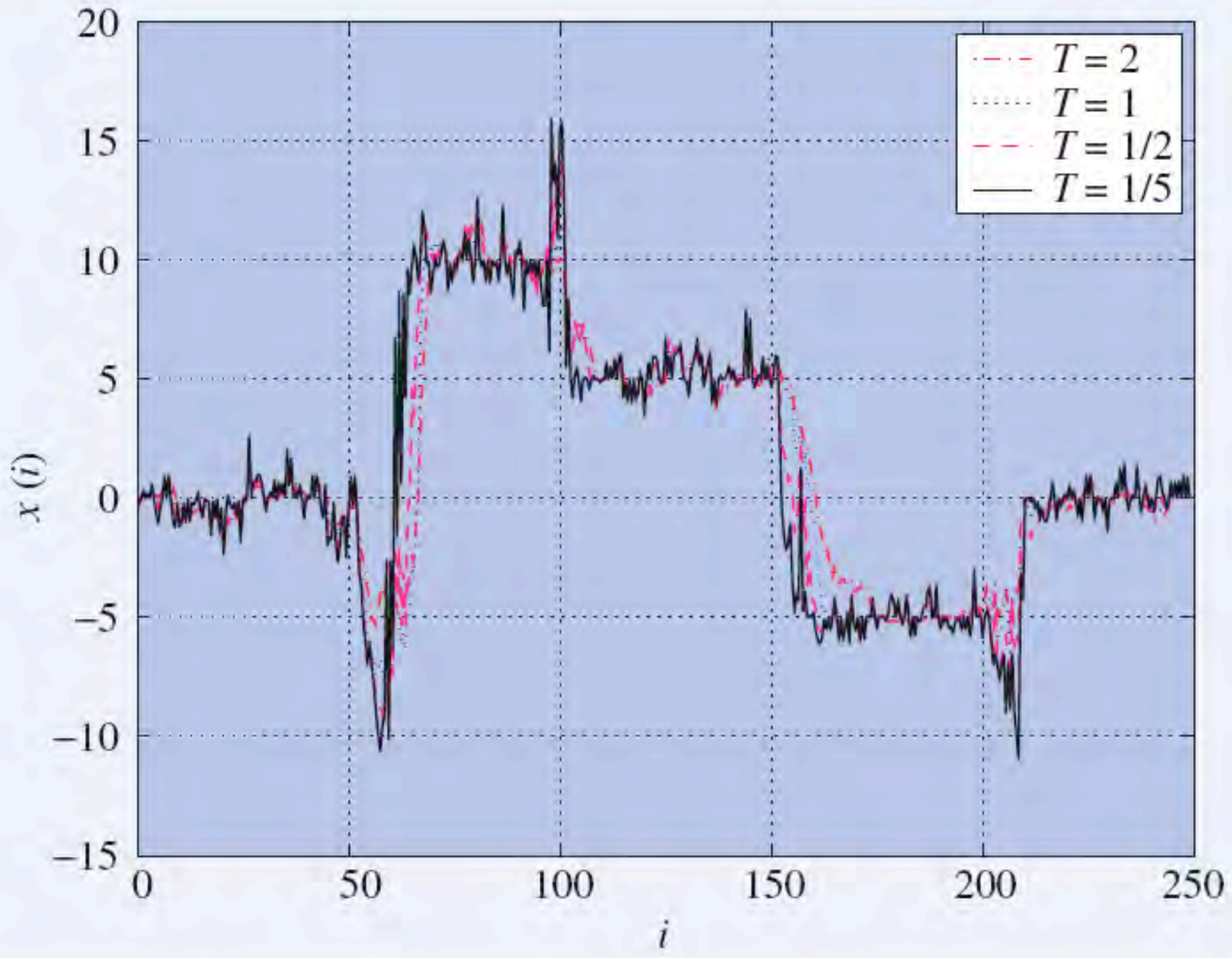
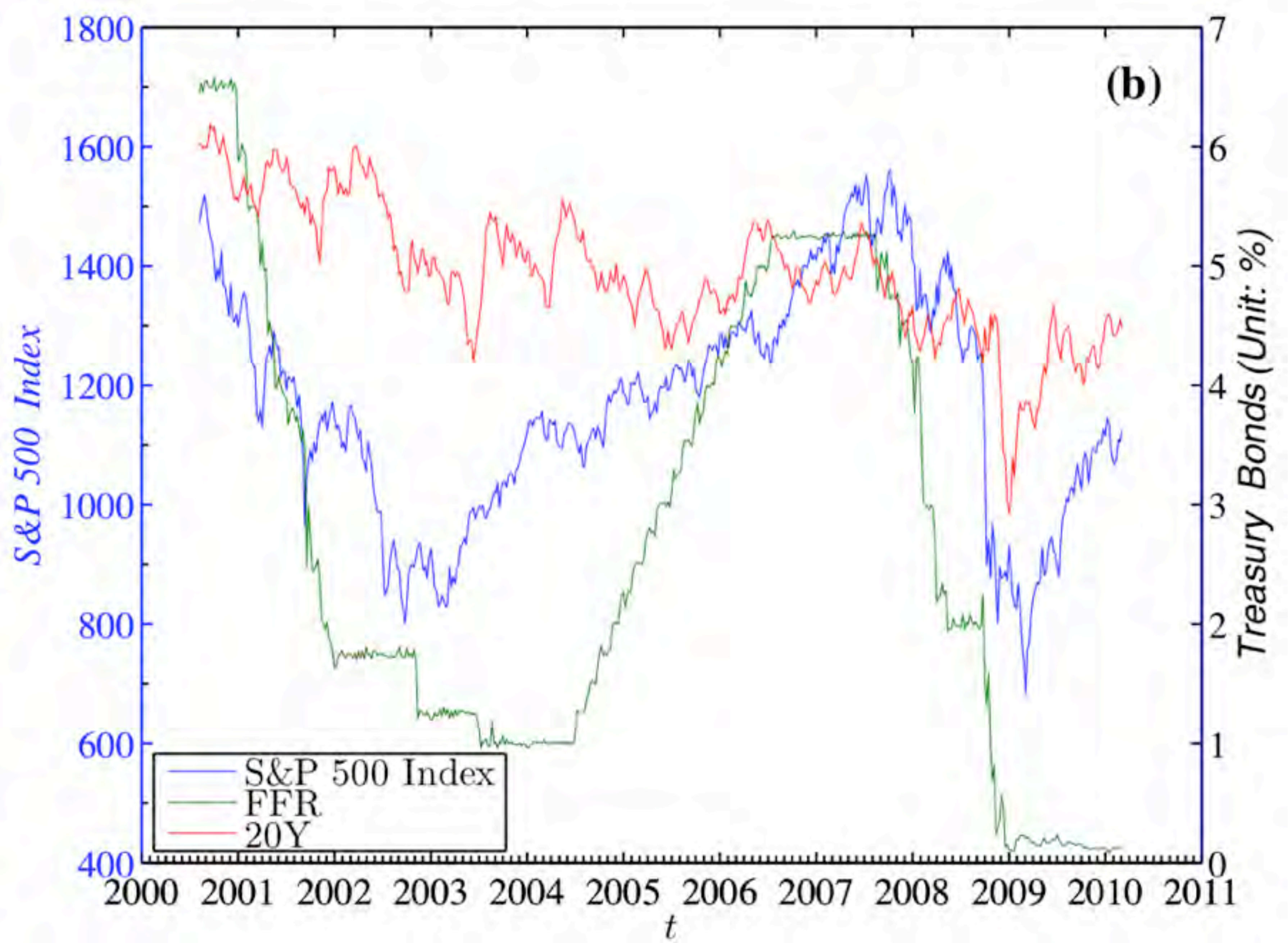
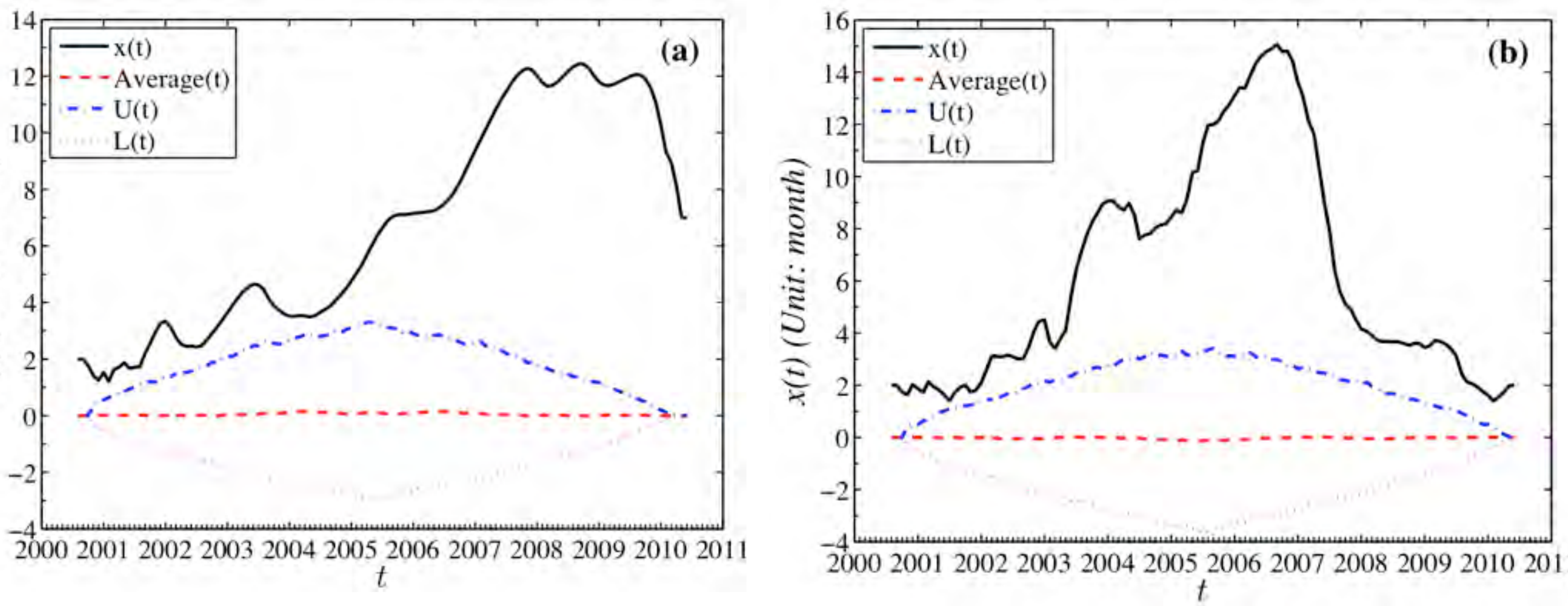


Figure 8. Average thermal path (transverse trajectory $x(i)$ as a function of the coordinate i along the main diagonal) starting at the origin, for four different temperatures ($T=2$ (dotted-dash), $T=1$ (dotted), $T=0.5$ (dashed) and 0.2 (continuous)) obtained by applying the optimal thermal causal path method to the synthetic time series (12) with (9).



S&P 500 and FFR together with the 20Y for comparison.

Bootstrap significance tests



FFR

20Y Treasury bond yield

Bootstrap test for the significance of the lead-lag structure for the FFR and the 20Y Treasury bond yield.

TEXTBOOK WISDOM:

(i) the stock market variations and the yield changes should be anti-correlated;

(ii) the change in FFR, as a proxy of the monetary policy of the central bank, should be a predictor of the future stock market direction.

OUR RESULTS:

(1) The stock market and yields move in the same direction (confirming R. Werner)

(2) The stock market leads the yields, including and especially the FFR.

(3) Inversion of lead-lag structure between short-term and long-term yields after the crisis erupted.

Out-of-equilibrium nonlinear financial economics

- Financial bubble experiments at ETH Zurich

- Reverse engineering of financial markets with agent-based models

- Illusion of control

- Multifractal endogenous econometric models for augmented variance estimators and forecasting

- Time-dependent lead-lag in econometrics

- **Quantum decision theory**

Partial list of problems with standard Utility theory

- Allais paradox (Compatibility violation: Several choices are not compatible with utility theory)
- Ellsberg paradox (uncertainty aversion)
- Kahneman-Tversky paradox (invariance violation)
- Rabin paradox (payoff size effects)
- Disjunction effect (violation of the sure-thing principle)
- Conjunction fallacy (violation of probability theory)

“Bounded rationality”

- In 1957, Herbert Simon described the principle of “bounded rationality” - Nobel Prize in 1978:

  > “The capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problem whose solution is required for objectively rational behavior in the real world, or even for a reasonable approximation to such objective rationality.”

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What to do?

1. Realistic problems are complicated, consisting of many parts.
2. Different parts of a problem interact and interfere with each other.
3. Several thoughts of mind can be intricately interconnected (entangled).

Life is complex!

=>Towards a fundamental theory of human decision making

(triune brain: reptilian, emotional, rational)

Quantum Decision Theory?

V.I. Yukalov and D. Sornette
Processing Information in Quantum Decision Theory,
Entropy 11, 1073-1120 (2009)

V.I. Yukalov and D. Sornette
Entanglement Production in Quantum Decision Making,
Physics of Atomic Nuclei 73 (3), 559-562 (2010).

Quantum Decision Theory

- Novel approach to decision making is developed based on a complex Hilbert space over a lattice of composite prospects.
- Risk of **loss and uncertainty** are taken into account.
- Decisions are probabilistic and depend on state of mind that can be changed or framed.
- Paradoxes of classical decision theory are explained.
- Good quantitative agreement with empirical data.
- Conjunction fallacy is a sufficient condition for disjunction effect.

Out-of-equilibrium nonlinear financial economics

- Financial bubble experiments at ETH Zurich
- Reverse engineering of financial markets with agent-based models
- Illusion of control
- Multifractal endogenous econometric models for augmented variance estimators and forecasting
- Time-dependent lead-lag in econometrics
- Quantum decision theory

Questions and Strategy for the future

“Nature” is more imaginative than mathematicians, economists or... econophysicists