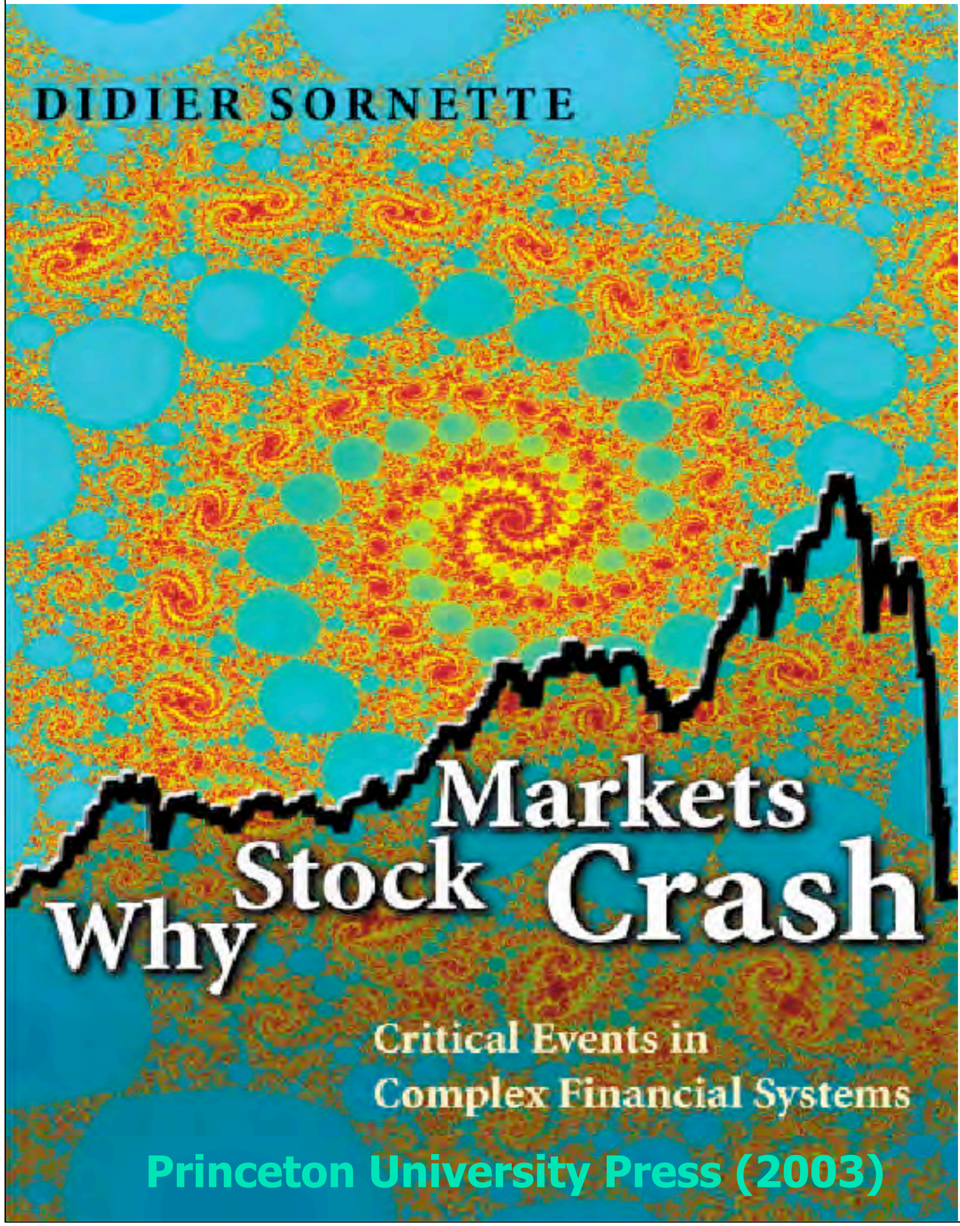
Physics and Financial Economics (1776-2009)



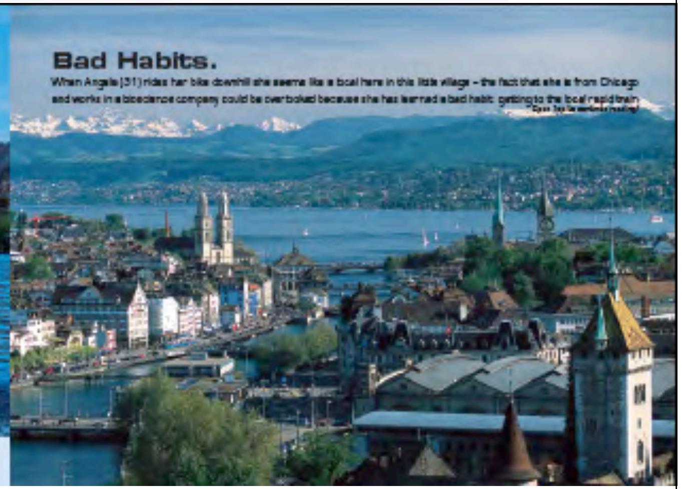
Chair of Entrepreneurial Risks

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

Member of the Swiss Finance Institute

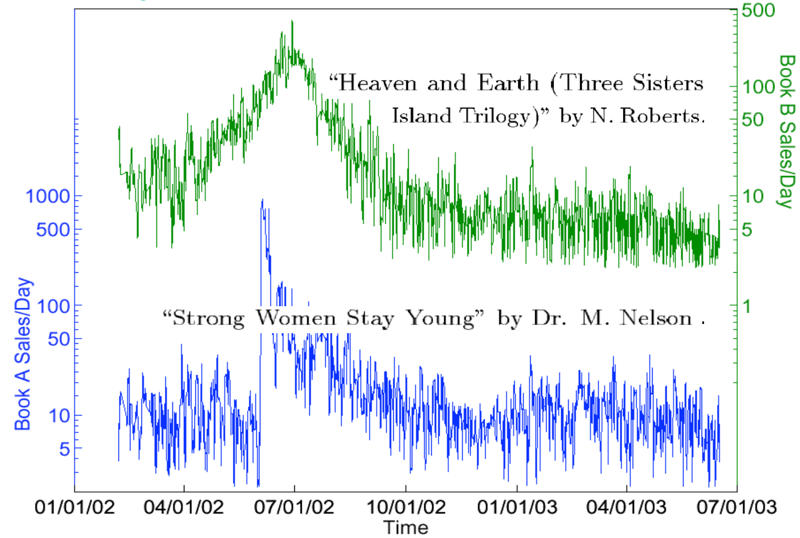
co-founder of the Competence Center for Coping with Crises in Socio-Economic Systems, ETH Zurich (http://www.ccss.ethz.ch/)

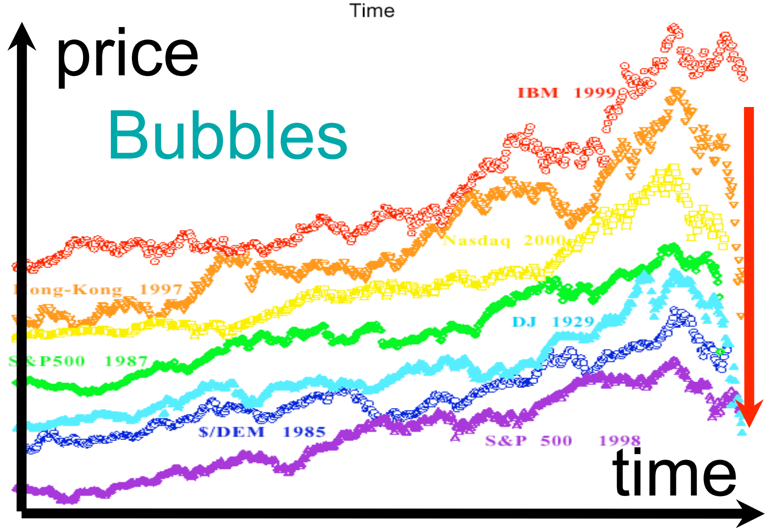
This is ETH Zurich → 12 700 students → 350 professors → 3600 other teaching and research staff → 2 campuses → 21 Nobel Prizes → 136 labs → 21% international students → 90 nationalities → 36 languages



- Collective dynamics and organization of social agents (Commercial sales,YouTube, Open source softwares, Cyber risks)
- Agent-based models of bubbles and crashes, credit risks, systemic risks
- Prediction of complex systems, stock markets, social systems
- Asset pricing, hedge-funds, risk factors…
- Human cooperation for sustainability
- Natural and biological hazards (earthquakes, landslides, epidemics, critical illnesses…)

Dynamics of success





(3 guest-professors, 5 foreign associate professors,
3 post-docs, 2 senior researcher, 12 PhD students, 4-6 Master students)

ECONOMICS		PHYSICS
Adam Smith “Inquiry into the Nature and Causes of the Wealth of Nations” (1776)	←	•Isaac Newton Philosophiae Naturalis Principia Mathematica (1687) [(novel at the time) notion of causative forces]
•Francis Edgeworth and Alfred Marshall (1890) develop the concept of equilibrium	←	•Clerk Maxwell and Ludwig Boltzmann (1871-1875): equilibrium in gases
•“everything in the economy affects everything else”	↔	•mean-field theory or self-consistent effective medium methods
•Vilfredo Pareto (1897): power law distribution of incomes	→	•distribution of event sizes (earthquakes, avalanches, landslides, storms, forest fires, solar flares, commercial sales, war sizes, ...)
•Louis Bachelier (1900): random walk model of Paris stock market and solution of diffusion equation	→	•Einstein (1905): theory of Brownian motion
•Benoit Mandelbrot (1963) proposes heavy-tailed distributions (Levy stable laws) for the pdf of cotton returns	→	•Benoit Mandelbrot (1977): Fractals
•initially supported by Merton Miller, Eugene Fama, and Richard Roll (Chicago), Paul Samuelson (MIT), and Thomas Sargent (Carnegie Mellon), but opposition from Paul Cootner and Clive Granger; •distributions of returns are becoming closer to the Gaussian law at timescales larger than one month.	>	•Much of the efforts in the econophysics (1993-2000s) refined the Levy hypothesis into $$\mathrm{pdf}(r) \sim 1/r^3$$

ECONOMICS

PHYSICS

Adam Smith (1776)
"Inquiry into the Nature and Causes of the Wealth of Nations"

←

Isaac Newton (1687)

Philosophiae Naturalis Principia Mathematica

notion of causative forces

(novel at the time)

ECONOMICS

PHYSICS

Francis Edgeworth and Alfred Marshall (1890) develop the concept of equilibrium

←

Clerk Maxwell and Ludwig Boltzmann (1871-1875)

equilibrium in gases

"everything in the economy affects everything else"

↔

mean-field theory or self-consistent effective medium methods

Equilibrium

ECONOMICS

PHYSICS

Vilfredo Pareto (1897) power law distribution of incomes

→

distribution of event sizes (earthquakes, avalanches, landslides, storms, forest fires, solar flares, commercial sales, war sizes, ...)

Non-Gaussian heavy tailed distributions

ECONOMICS

PHYSICS

Louis Bachelier (1900)
random walk model of
Paris stock market and
solution of diffusion
equation

→

Einstein (1905)
theory of Brownian motion

Theory of random walks and diffusion equation

ECONOMICS

Benoit Mandelbrot (1963)
Heavy-tailed distributions (Levy stable laws) for the pdf of cotton returns

initially supported by Merton Miller, Eugene Fama, and Richard Roll (Chicago), Paul Samuelson (MIT), and Thomas Sargent (Carnegie Mellon), but opposition from Paul Cootner and Clive Granger

distributions of returns are becoming closer to the Gaussian law at timescales larger than one month.

PHYSICS

→

Benoit Mandelbrot (1977)
Fractals

Much of the efforts of econophysicists (1993-2000s) refined the Levy hypothesis into

$$\mathrm{pdf}(r) \sim 1/r^3$$

←

self-similarity

ECONOMICS		PHYSICS
-Paul Krugman (1996) “Self-organizing economy” -Brian Arthur (1992) Induction, out-of-equilibrium -Santa Fe Institute (1994-...)	←	P. W. Anderson (1957) “More is different” (1972) -Out-of-Equilibrium -frozen heterogeneity (spinglasses, glasses, proteins)

Out-of-equilibrium, frozen heterogeneity,

Self-organization, phase transitions ....

A partial lists of achievements of Econophysics

- scaling laws, “universality”
- agent-based models, induction, evolutionary models [1, 9, 11, 21],
- minority games [8],
- option theory for incomplete markets [4, 6],
- “string theory” of interest rate curves [5, 38],
- theory of Zipf law and its economic consequences [12, 13, 27],
- theory of large price fluctuations [14],
- theory of bubbles and crashes [17, 22, 40],
- random matrix theory applied to covariance of returns [20, 36, 37],
- methods and models of dependence between financial assets [25, 43].

G. Daniel and D. Sornette, Econophysics: historical perspectives, in the Encyclopedia of Quantitative Finance, edited by Rama Cont (www.wiley.com/go/eqf), Section: History of Quantitative Modeling (1st section out of 21), edited by Perry Mehrling and Murad Taqqu (http://arXiv.org/abs/0802.1416)

FOUR EXAMPLES

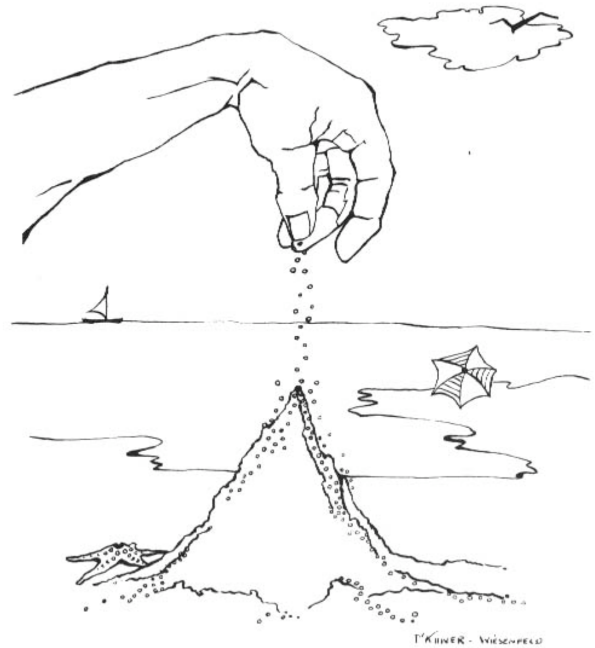
(i) the fluctuation-susceptibility theorem transforms into a remarkable classification of financial volatility shocks (endogenous versus exogenous),

(ii) the Ising model of phase transitions can be generalized to model the stylized facts of financial markets,

(iii) the concepts of collective phenomena and phase transitions (with spontaneous symmetry breaking) help understand financial bubbles and their following crashes,

(iv) the mathematics of quantum physics provides a new quantum decision theory solving the known paradoxes.

• **Self-organization?**
Extreme events are just part of the tail of power law distribution due to "self-organized criticality"? (endogenous)

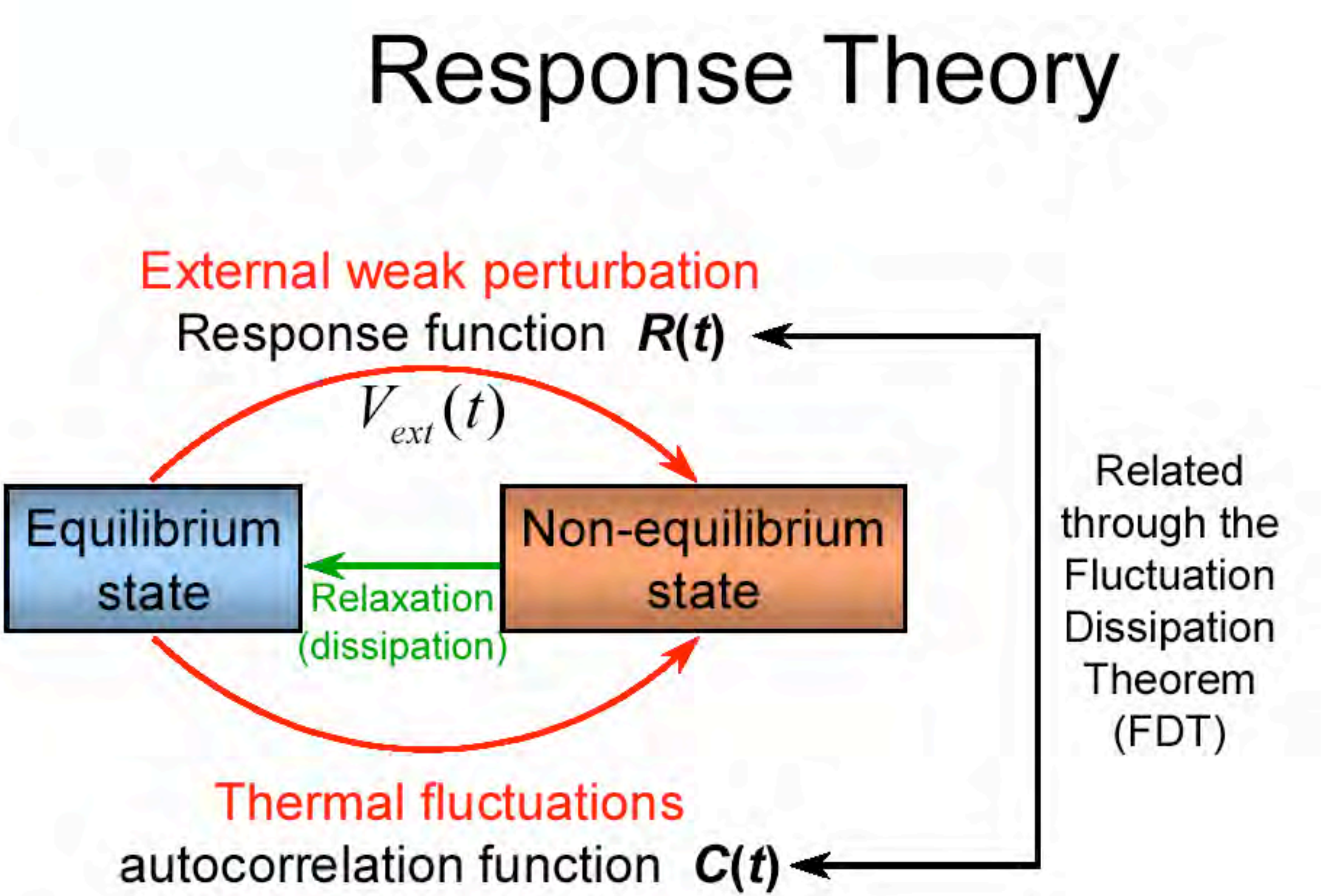


Artwork by Elaine Wiesenfeld
(from Bak, How Nature Works)

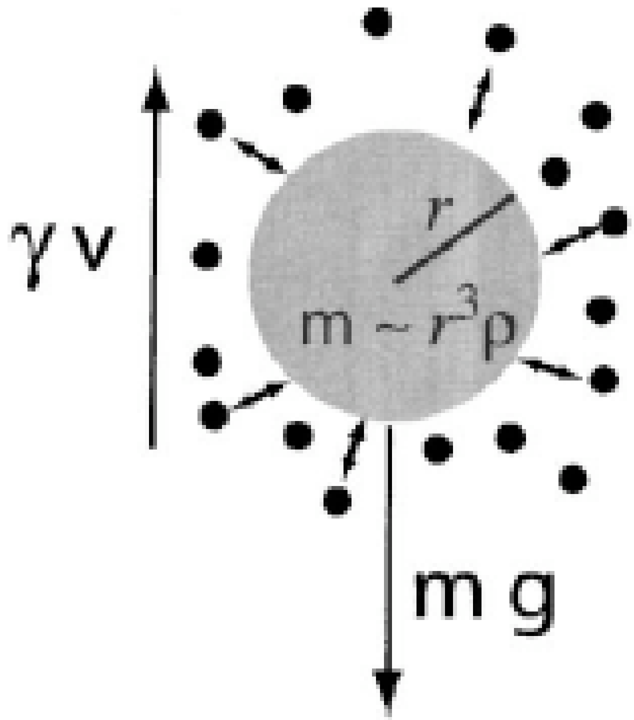
•**"Catastrophism": extreme events require extreme causes that lie outside the system (exogenous)**

•**A mixture? How would it work?**

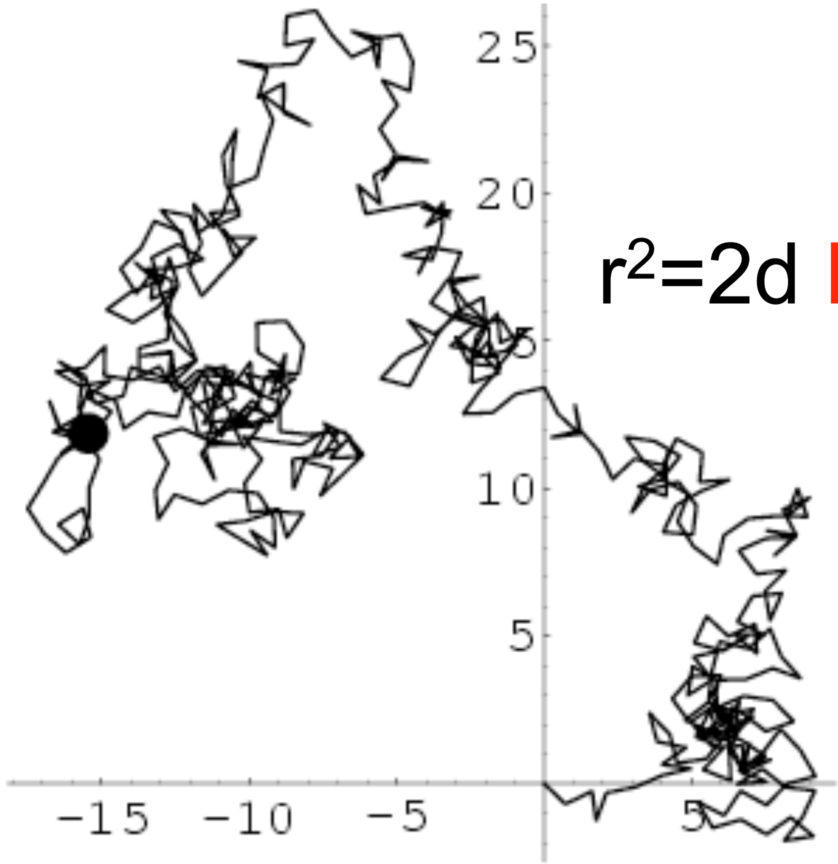
Guidelines from Physics: perturb and study the response



EXO:Drag resistance under an external force



ENDO: Random walk



$r^2=2d\,Dt$

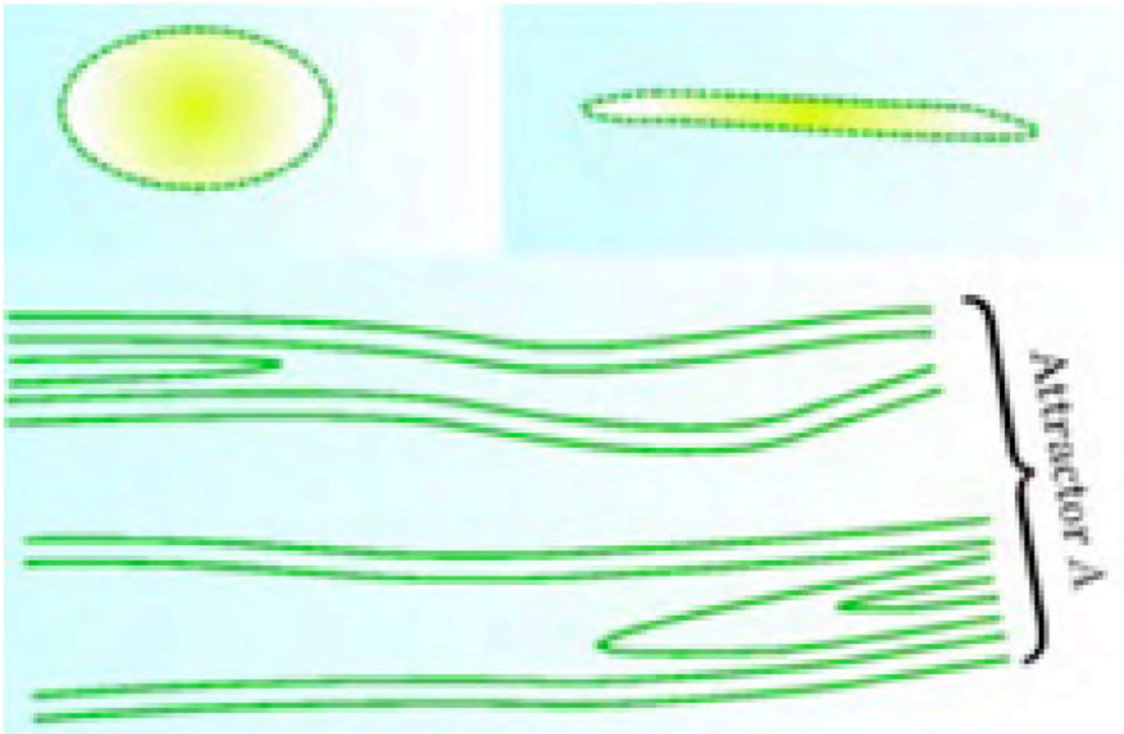
$$D=k_BT/\gamma$$

(Einstein, 1905)

Fluctuation-dissipation theorem far from equilibrium is not expected to hold

- Externally imposed perturbations may be different from spontaneous fluctuations (external fluctuations lie outside the complex attractor)

- Attractor of dynamics may exhibit bifurcations



D. Ruelle, Physics Today, May 2004

The method of critical events in economics and social sciences

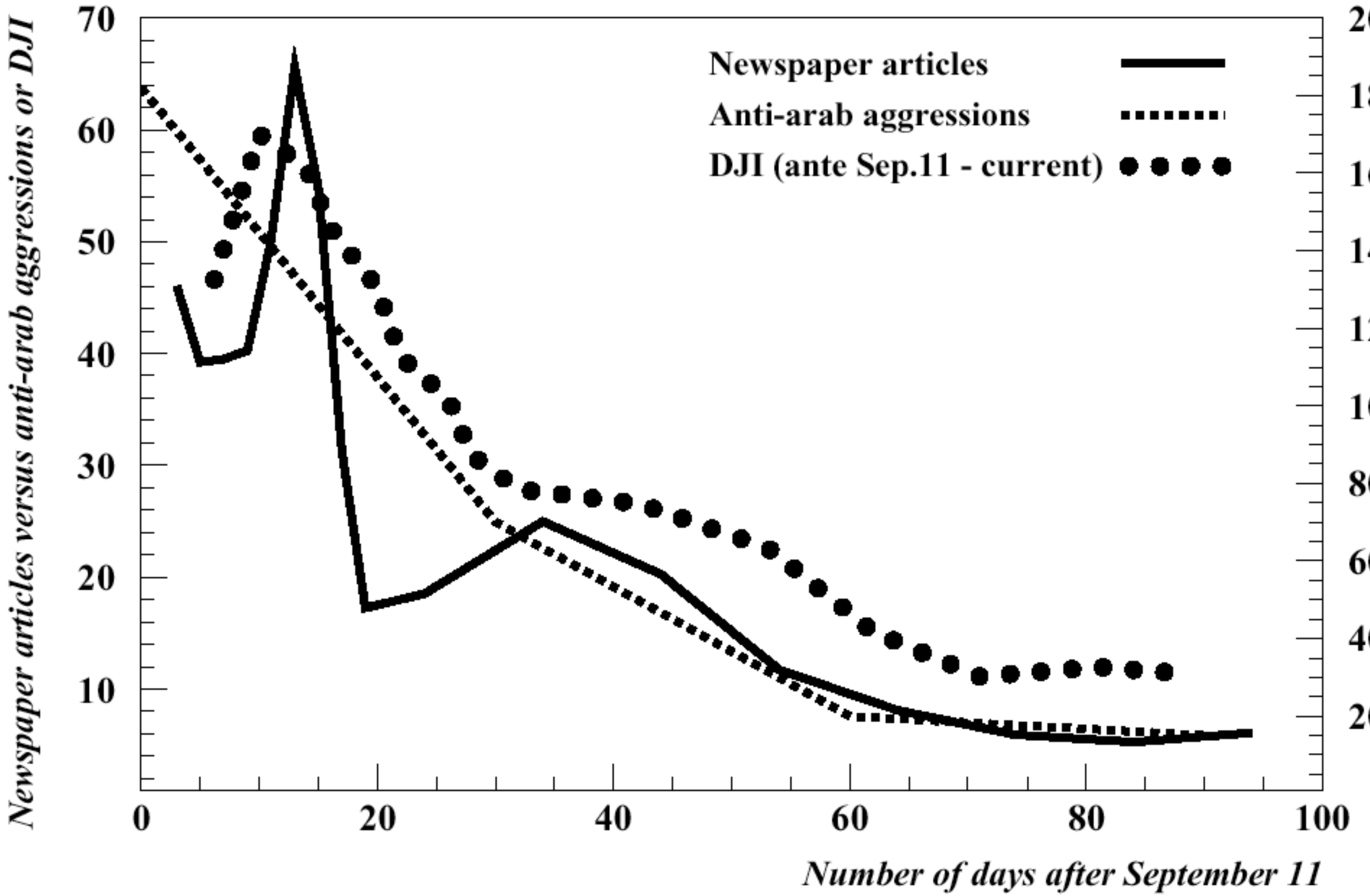
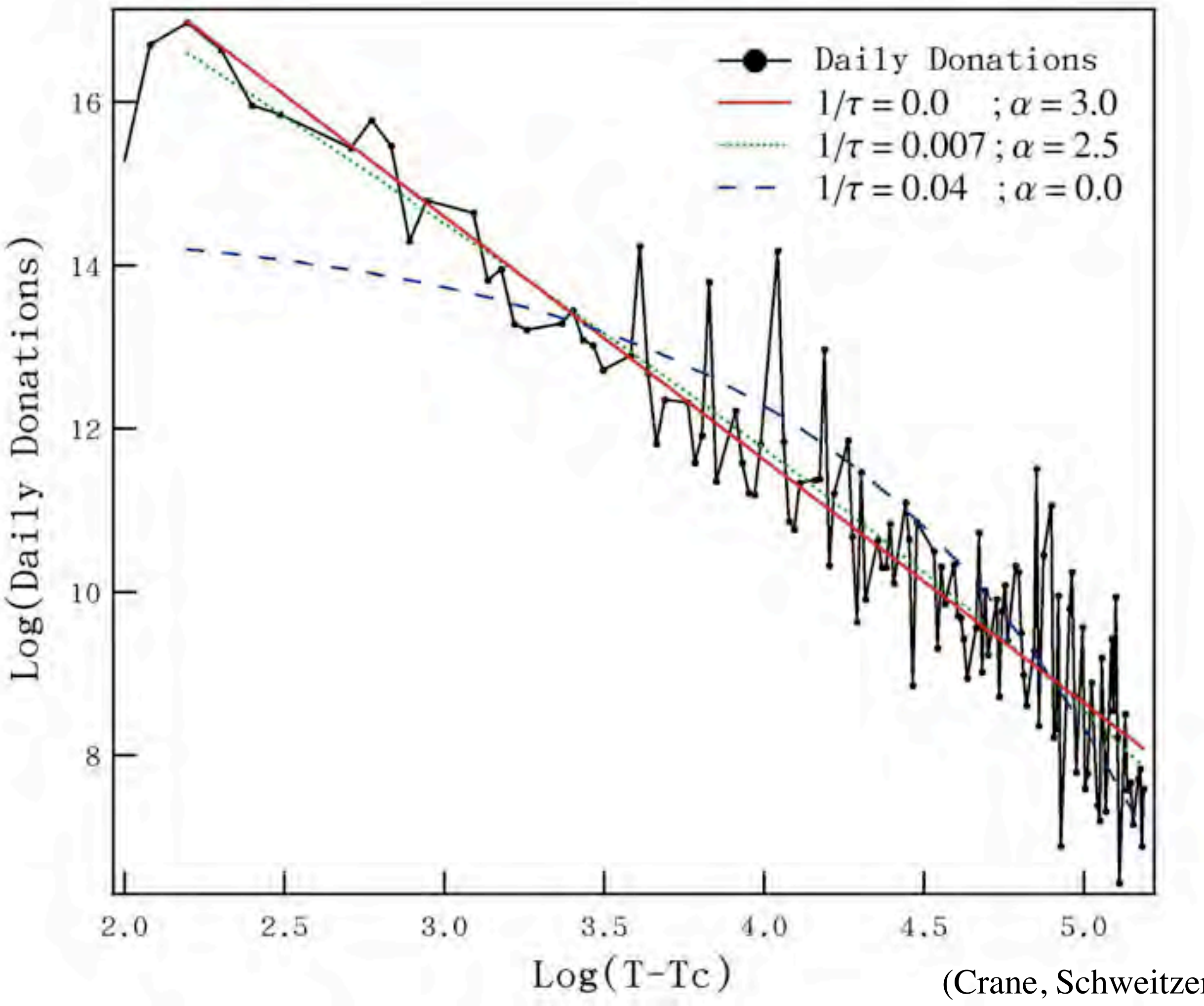


Fig.2: Relaxation curves after the shock of September 11. The solid line curve is the same as in Fig.1 but over a larger time interval; the broken line (scale on the right-hand side) shows the number of anti-arab aggressions in California in the three months after September 11; the dotted line shows the changes in the level of the Dow Jones Index with respect to its pre-Sep.11 level as given by the difference DJI(pre-9/11)-DJI(current). The tails of all three curves are well-approximated by power laws $\sim 1/t^{\alpha}$, with exponents α comprised between -1.4 and -2.2: $\alpha_1 = -1.8 \pm 0.7$ (newspaper articles), $\alpha_2 = -1.4 \pm 0.5$ (anti-arab agressions) and $\alpha_3 = -2.2 \pm 1.6$ (DJI).

(Roehner and Sornette, 2004)

Daily number of donations following the Asian Tsunami of December 26, 2004



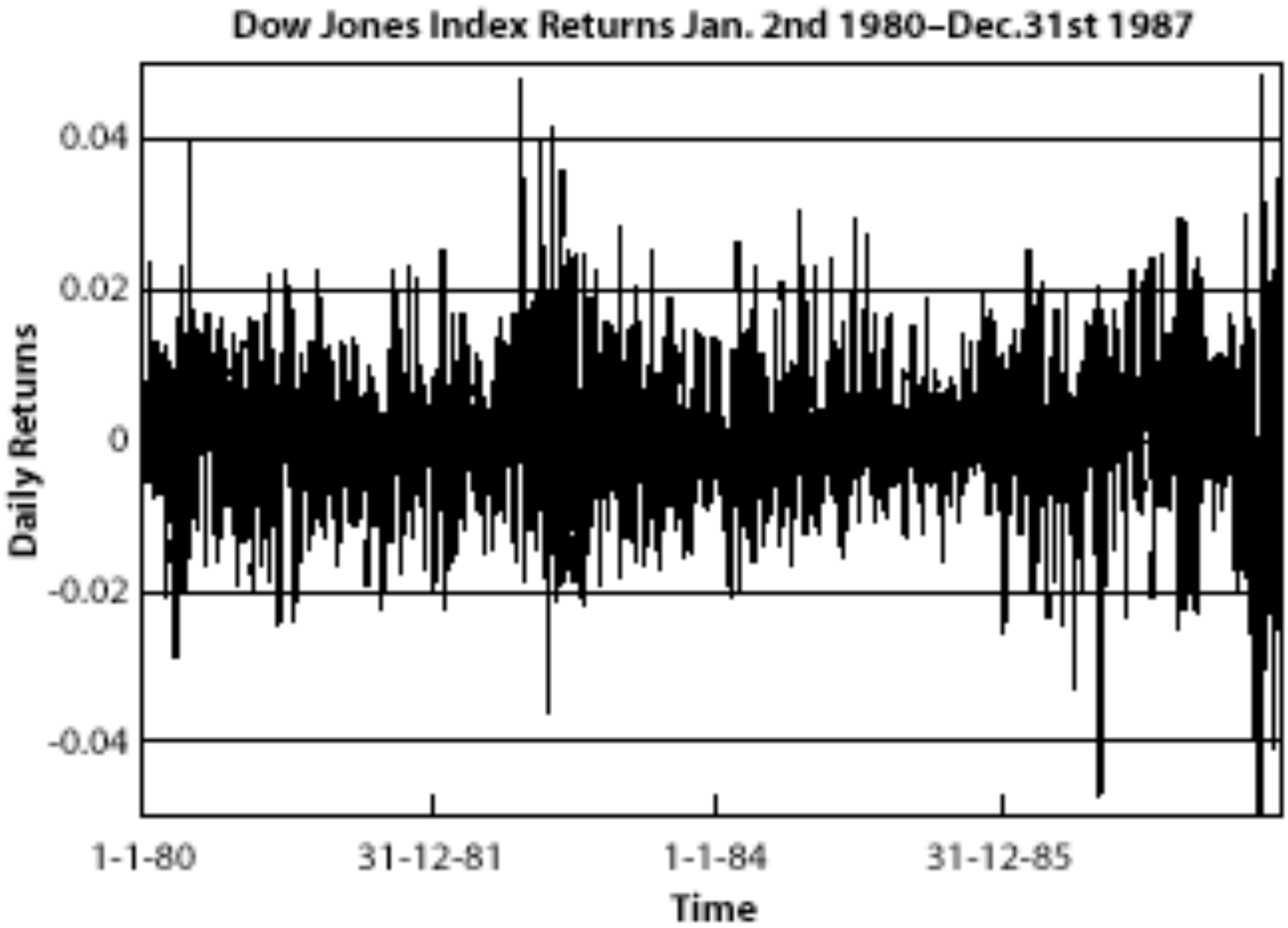
(Crane, Schweitzer and Sornette, 2009)

FINANCIAL SHOCKS

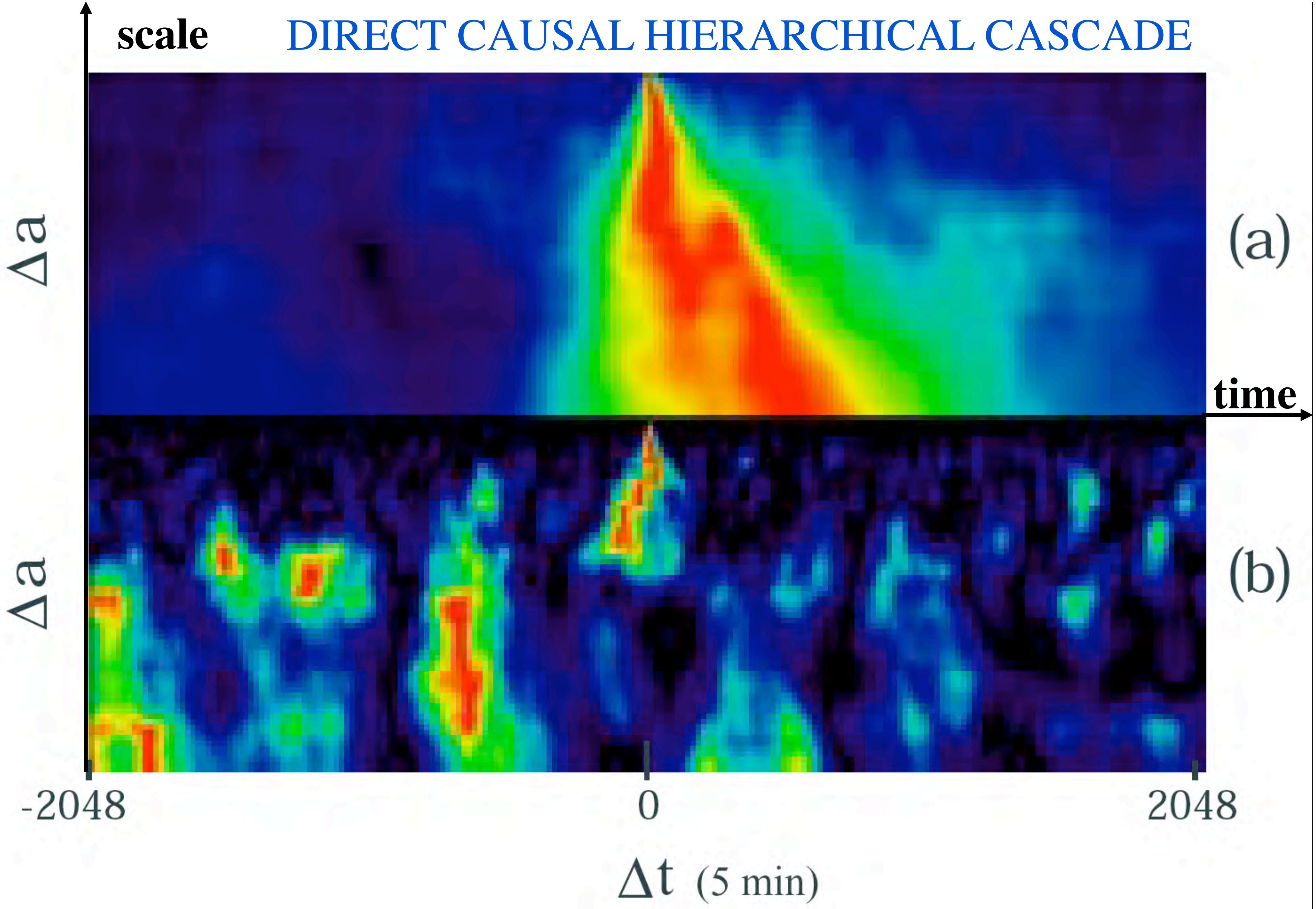
FIG. 1.8. Top panel: Time series of daily closes and volume of the Lucent Technology stock over a one-year period around the large drop of January 6, 2000. The time of the crash can be seen clearly as coinciding with the peak in volume (bottom panel). Taken from http://finance.yahoo.com/.

(Sornette, 2003)

Volatility


Dow Jones Index Returns Jan. 2nd 1980–Dec.31st 1987
Daily Returns
0.04
0.02
0
-0.02
-0.04
1-1-80
31-12-81
1-1-84
31-12-85
Time

DIRECT CAUSAL HIERARCHICAL CASCADE

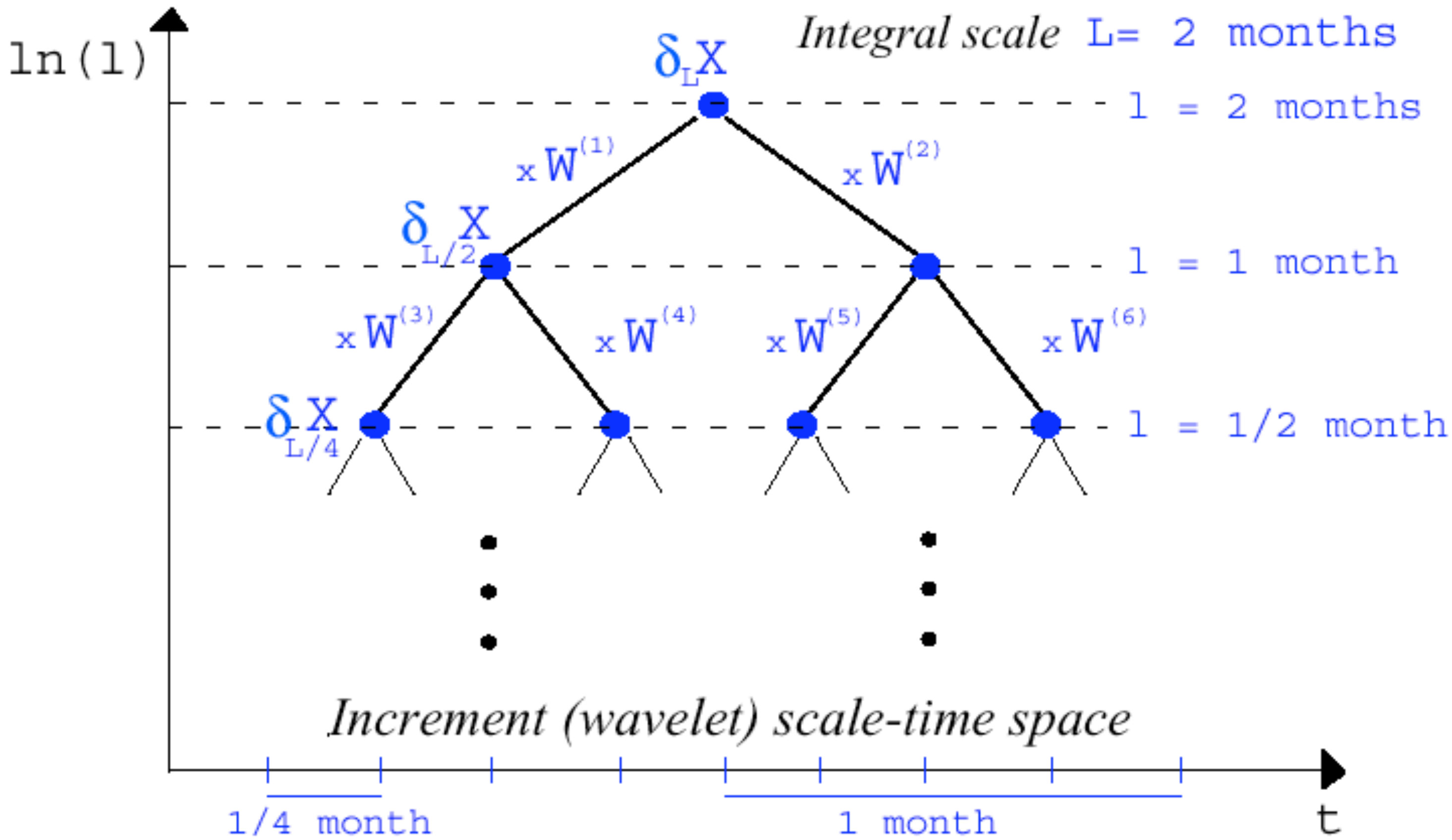


A. Arneodo, J.-F. Muzy and D. Sornette, Direct causal cascade in the stock market, European Physical Journal B 2, 277-282 (1998)

The multiplicative cascade paradigm

$$\delta_{\lambda l} X(\lambda t) = \lambda^H \delta_l X(t) = W_\lambda \delta_l X(t)$$

- $\mathcal{W}$-cascades (wavelet cascade)



The Multifractal Random Walk (MRW) model

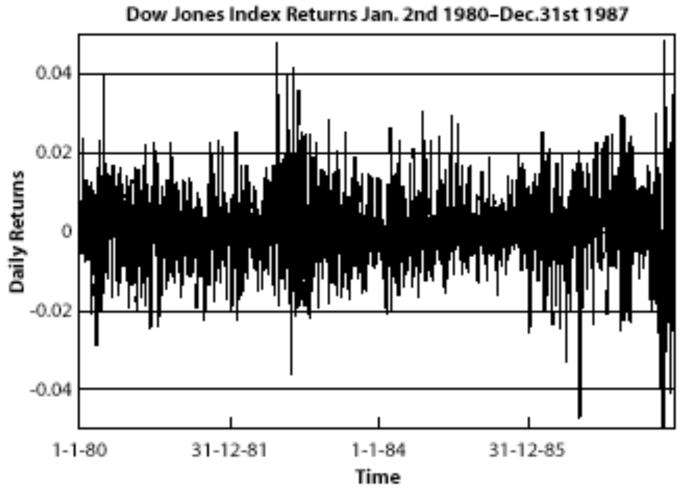
$$r_{\Delta t}(t) = \epsilon(t) \cdot \sigma_{\Delta t}(t) = \epsilon(t) \cdot e^{\omega_{\Delta t}(t)}$$

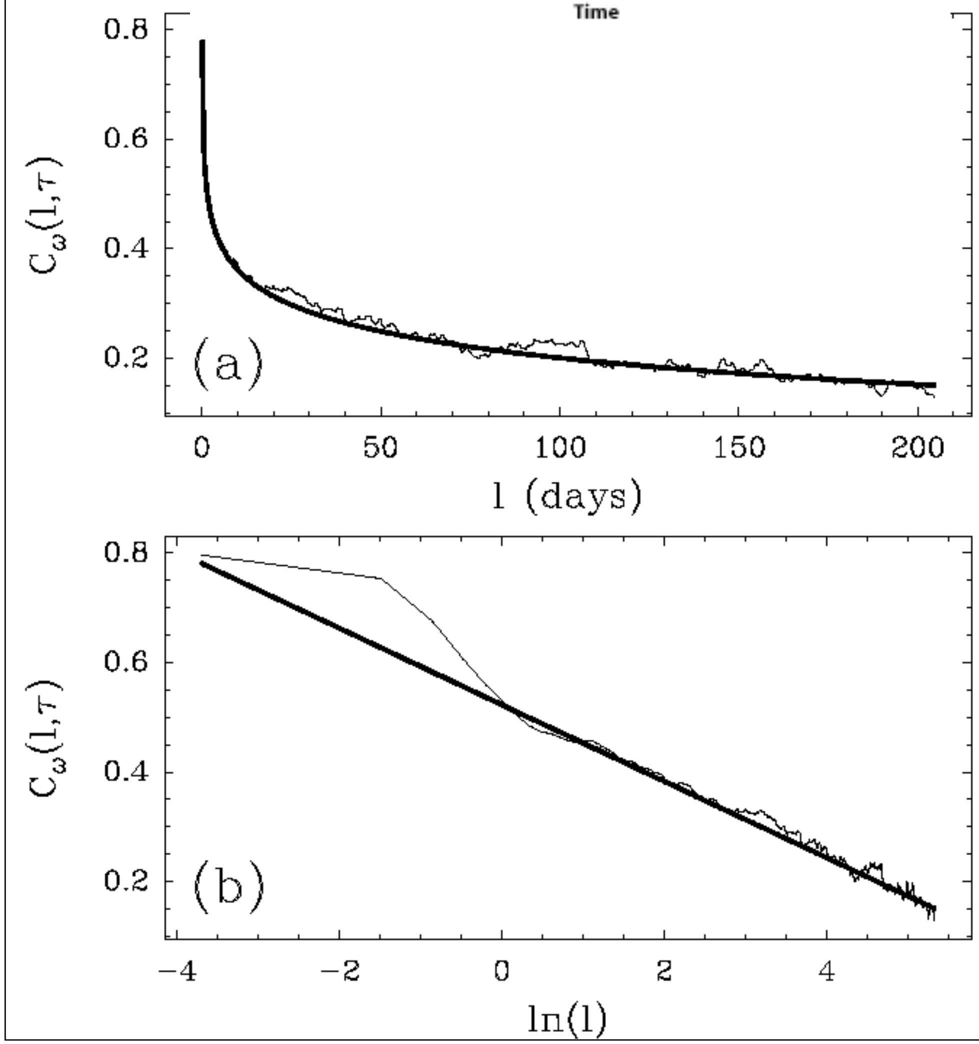
$$\omega_{\Delta t}(t) = \mu_{\Delta t} + \int_{-\infty}^{t} d\tau \; \eta(\tau) \; K_{\Delta t}(t-\tau)$$

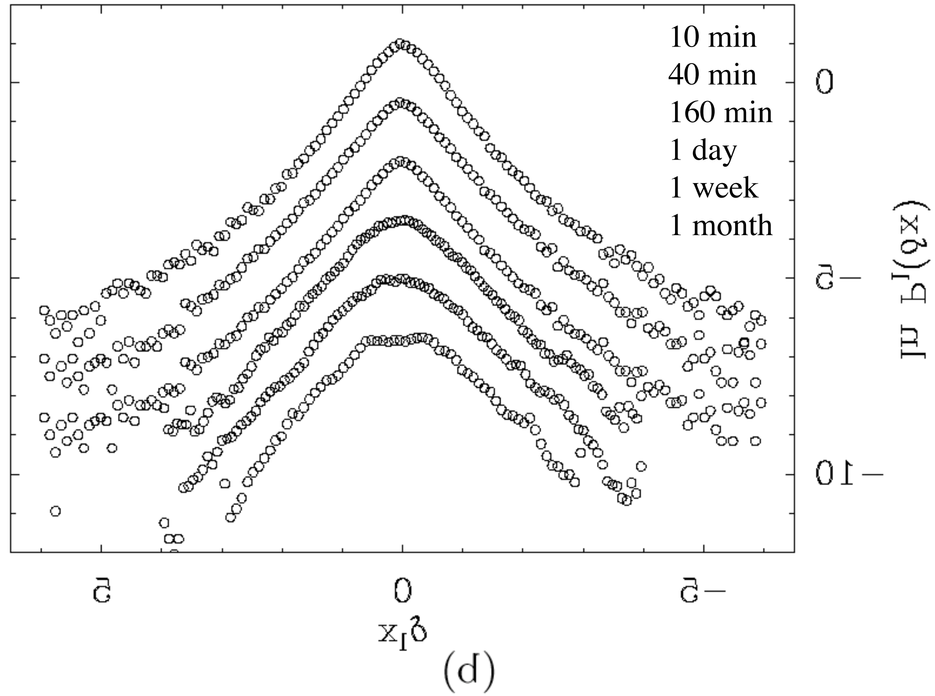
$$K_{\Delta t}(\tau) \sim K_0 \sqrt{\frac{\lambda^2 T}{\tau}} \quad \text{for } \Delta t << \tau << T$$

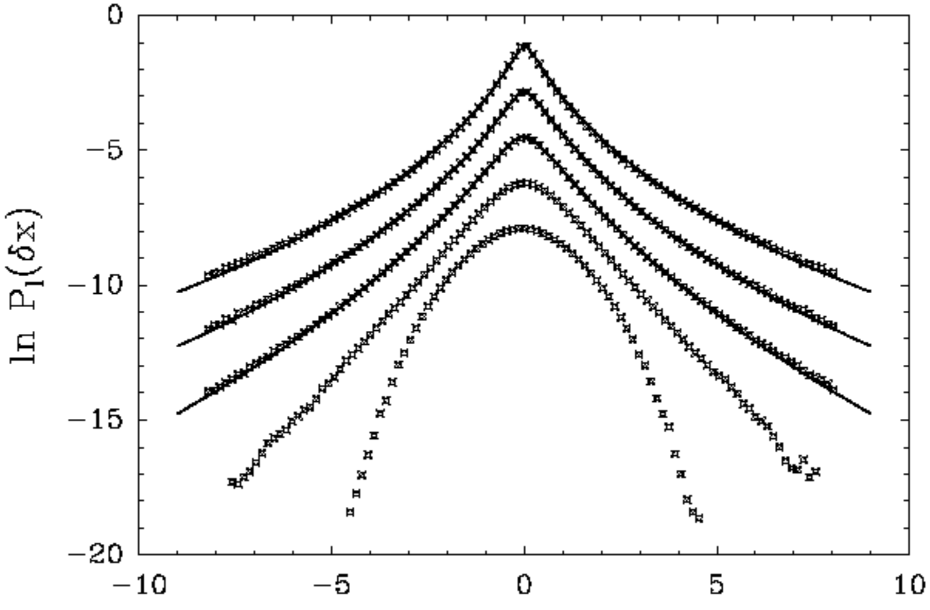
D. Sornette, Y. Malevergne and J.F. Muzy, Volatility fingerprints of large shocks: Endogeneous versus exogeneous, Risk 16 (2), 67-71 (2003)((http://arXiv.org/abs/cond-mat/0204626)

Stylized facts in financial markets



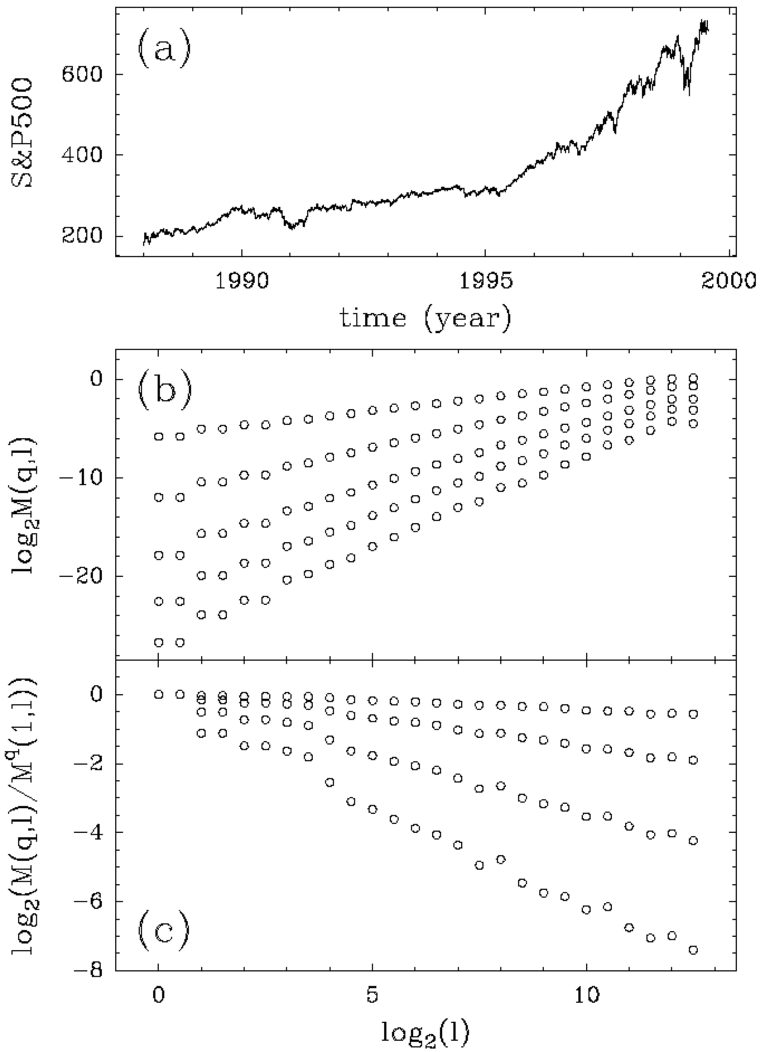






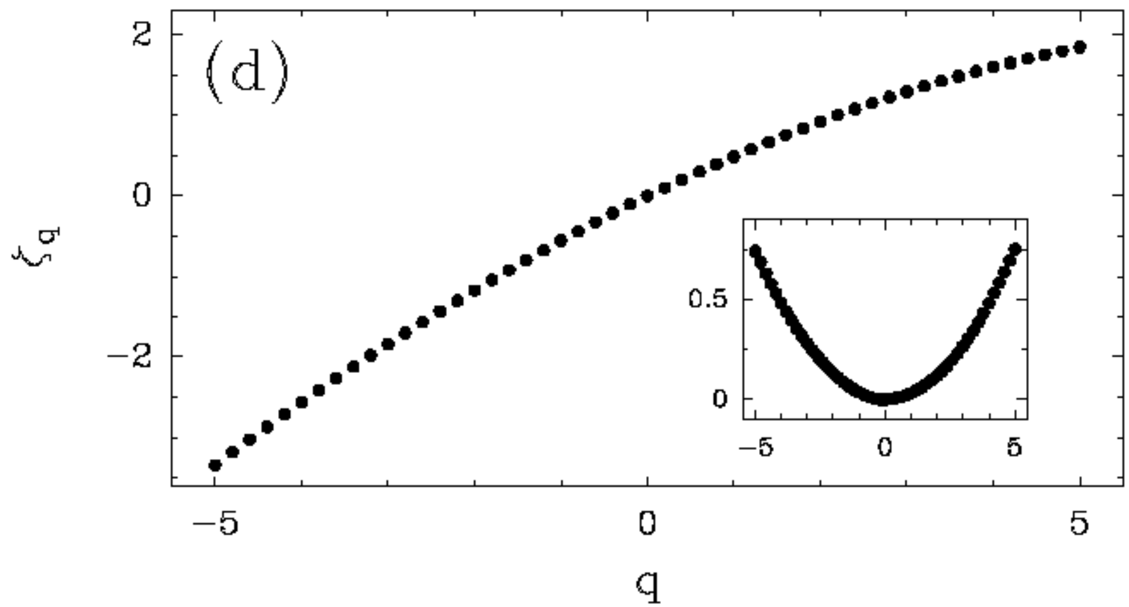
Multifractal random walk

Multifractality: $\langle [\delta_\tau X(t)]^q \rangle = a(q)\,\tau^{\zeta(q)}, \quad \text{for } \tau < T.$



$$\zeta(q) = \left(1 + \frac{\lambda^2}{2}\right) q - \frac{\lambda^2}{2} q^2$$

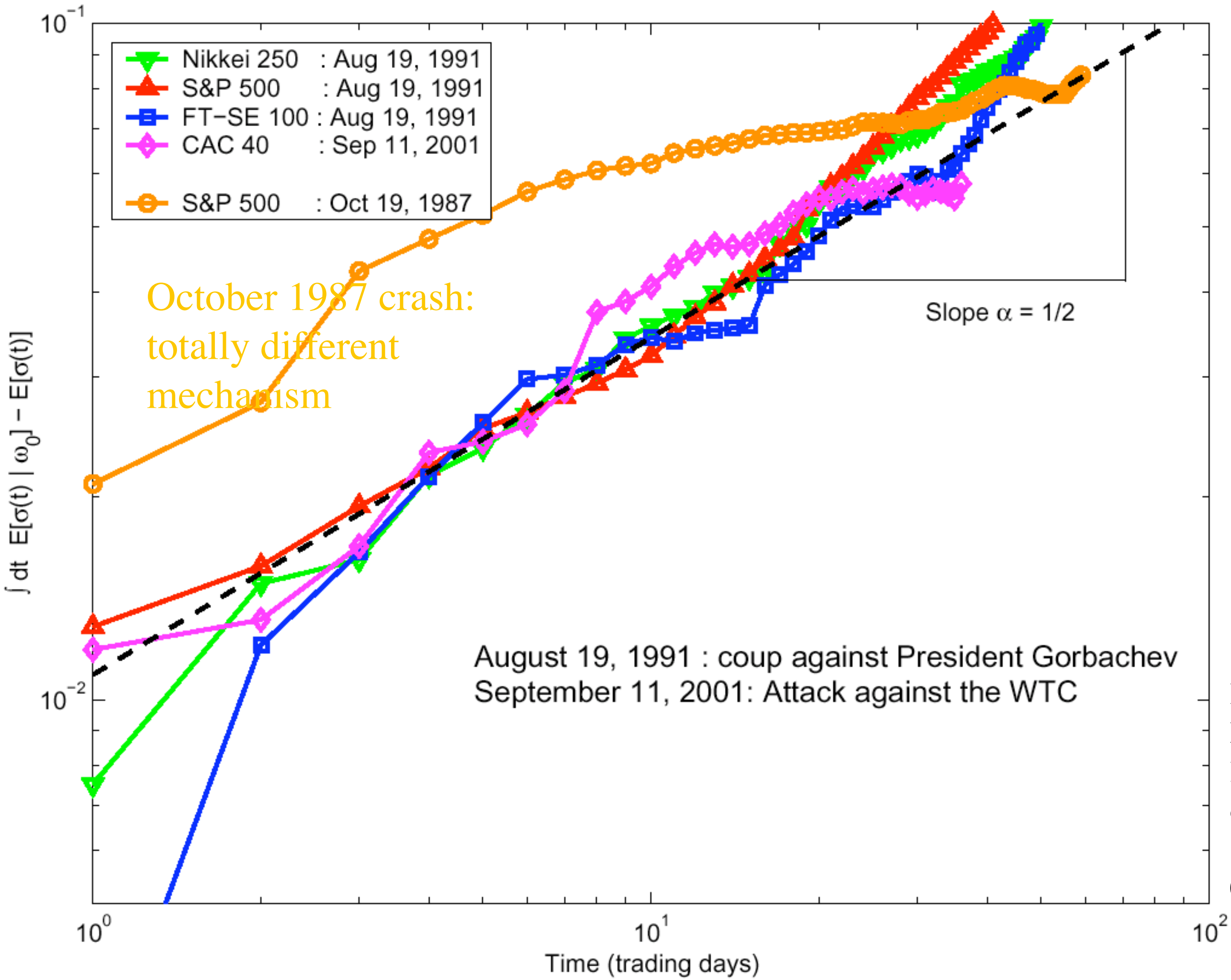
$\lambda^2 = -\zeta''(0)$ is the so-called *intermittency coefficient*.



Linear response to an external shock

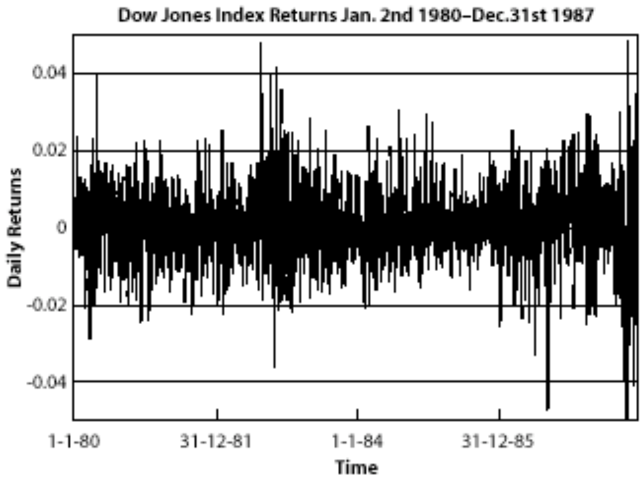
(Multifractal Random Walk model)

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



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

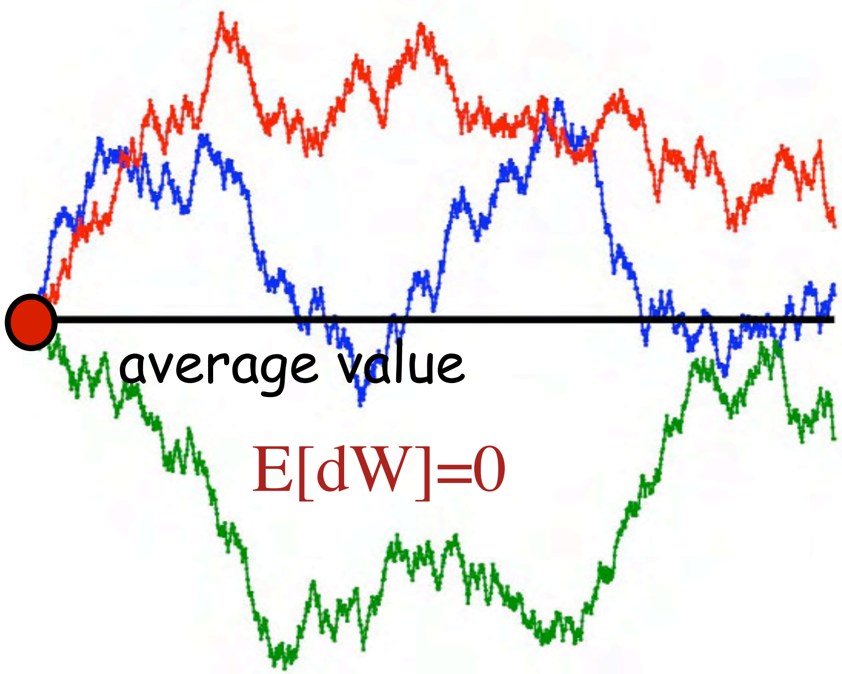
$$\mathrm{E}_{\mathrm{endo}}[\sigma^2(t) \mid \omega_0] \sim t^{-\alpha(s)}$$

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

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)

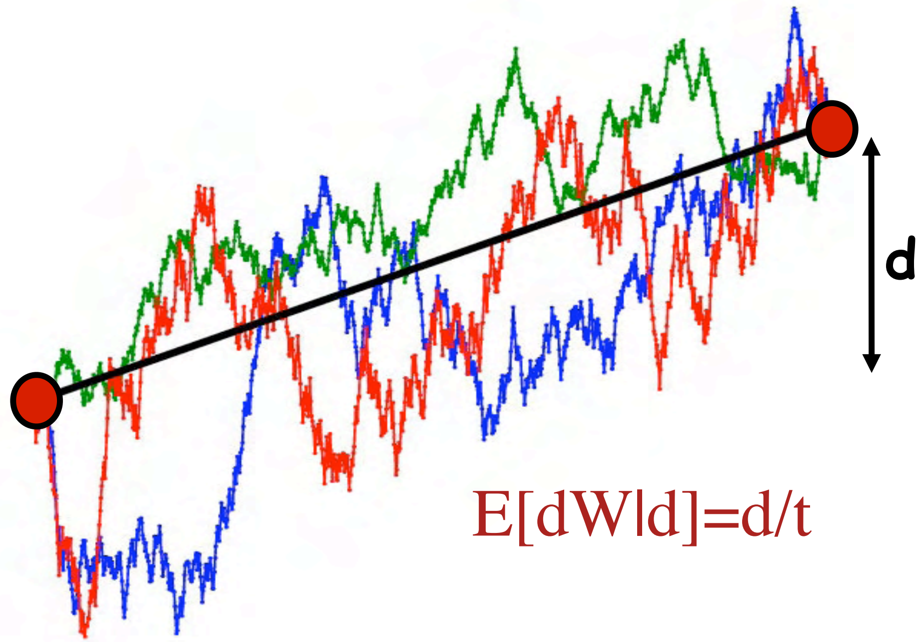
Analogy with Brownian motion

without conditioning:
stationary process, average=0



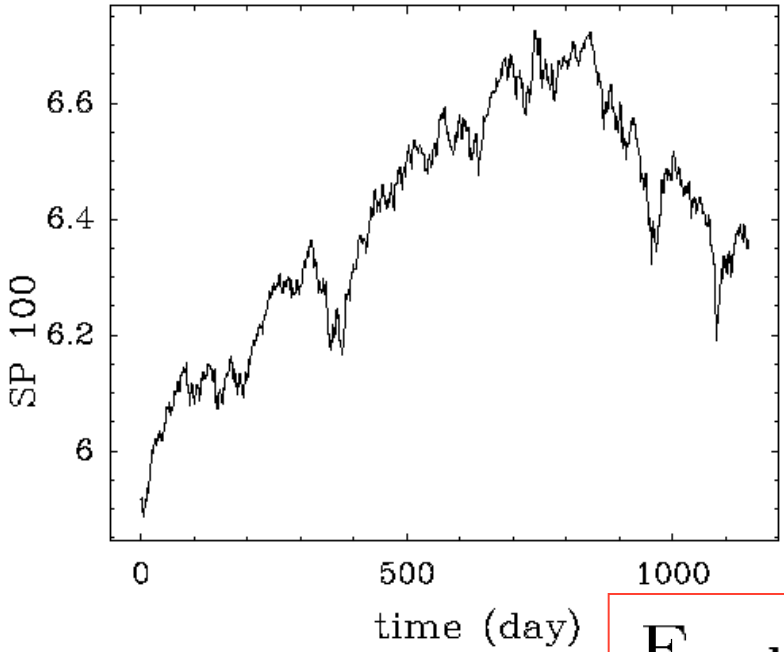
Stationary volatility

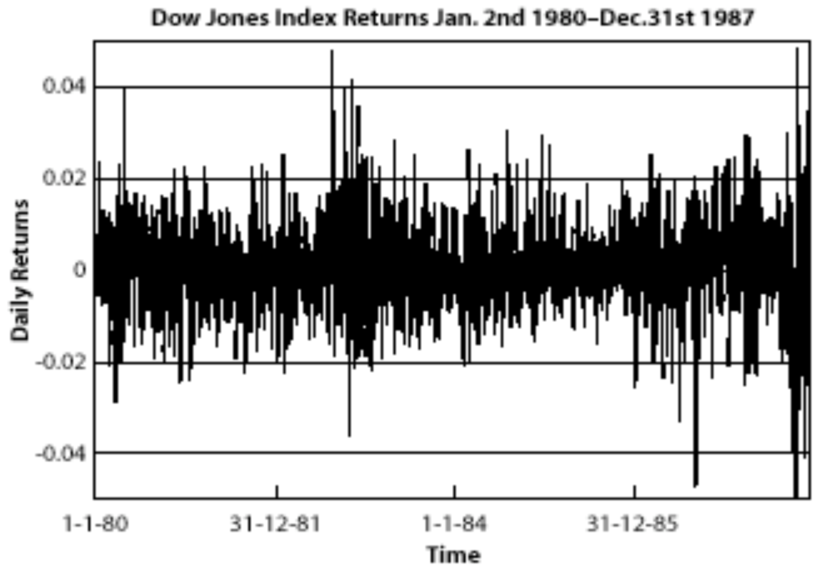
conditioning to a large value **W(t)=d** :
non-stationary process, average # 0



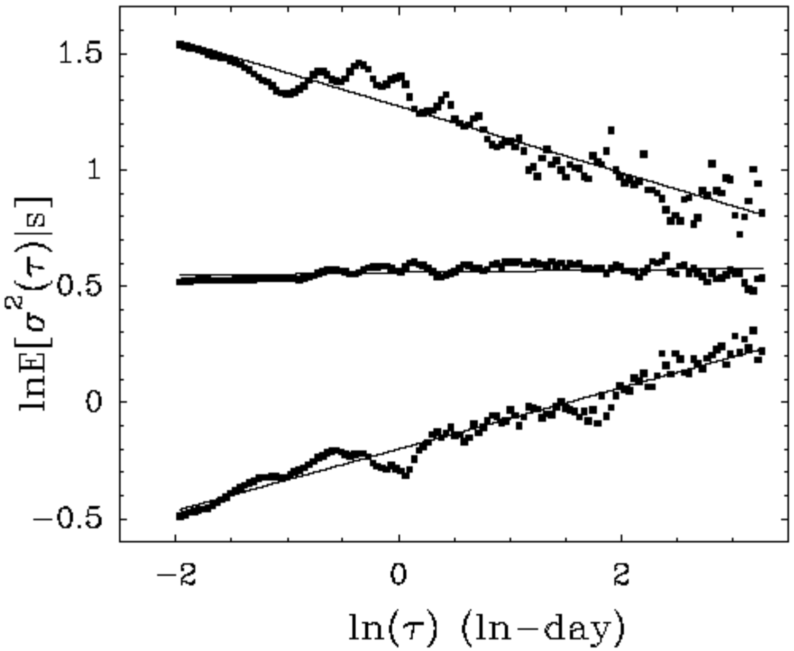
Volatility conditioned on an endogenous shock

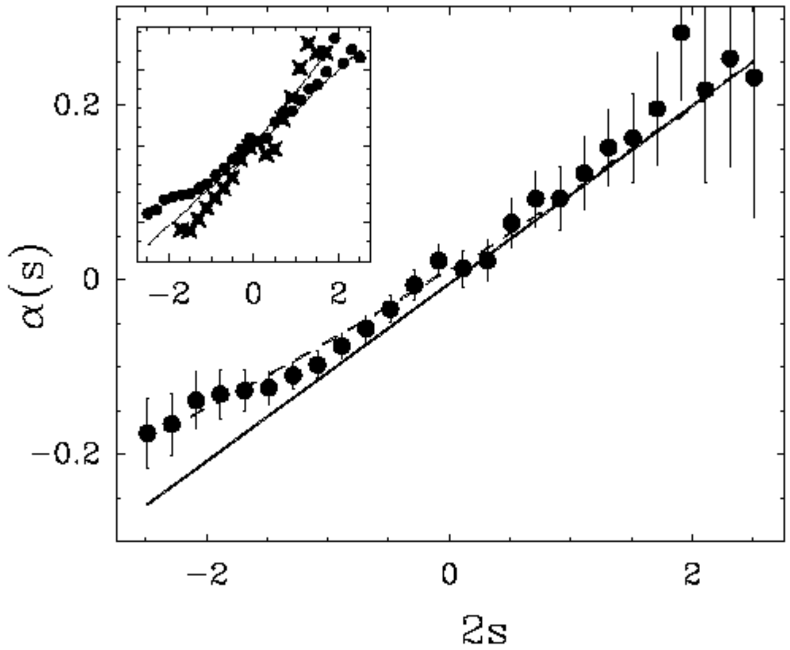
Real Data and Multifractal Random Walk model



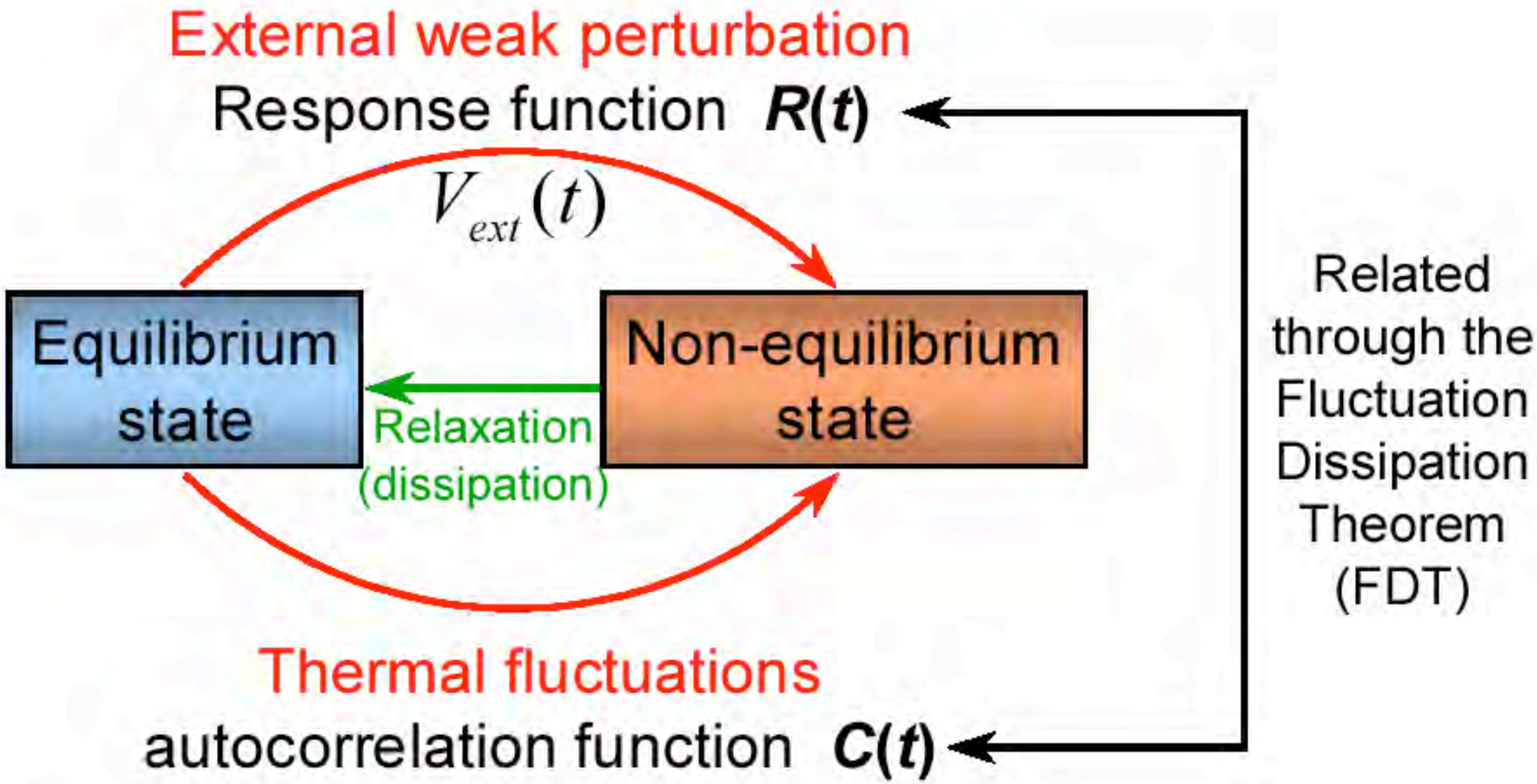


$$\mathrm{E}_{\mathrm{endo}}[\sigma^2(t) \mid \omega_0] \sim t^{-\alpha(s)}$$





Response Theory



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

FOUR EXAMPLES

(i) the fluctuation-susceptibility theorem transforms into a remarkable classification of financial volatility shocks (endogenous versus exogenous),

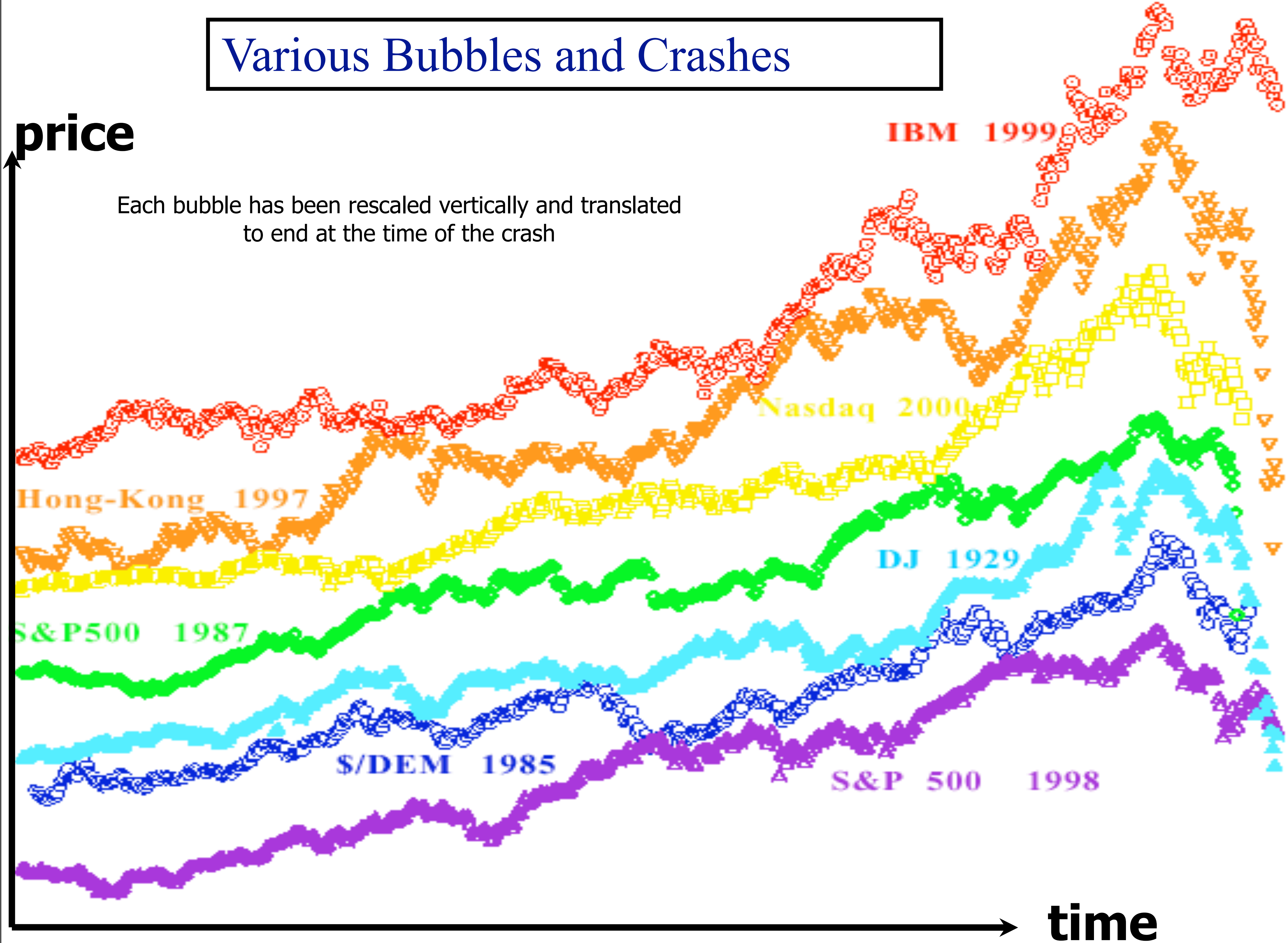
(ii) the Ising model of phase transitions can be generalized to model the stylized facts of financial markets,

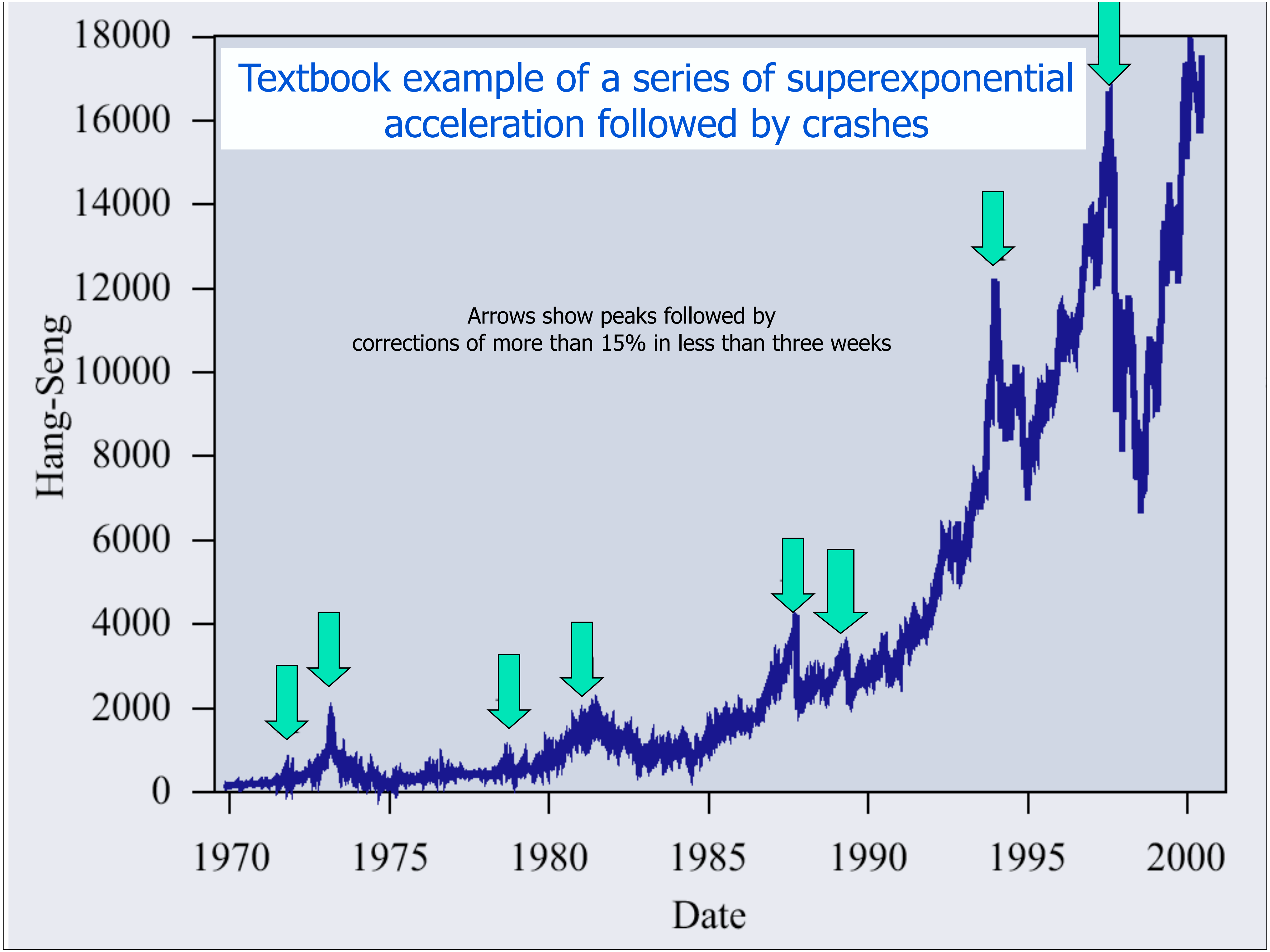
(iii) the concepts of collective phenomena and phase transitions (with spontaneous symmetry breaking) help understand financial bubbles and their following crashes,

(iv) the mathematics of quantum physics provides a new quantum decision theory solving the known paradoxes.

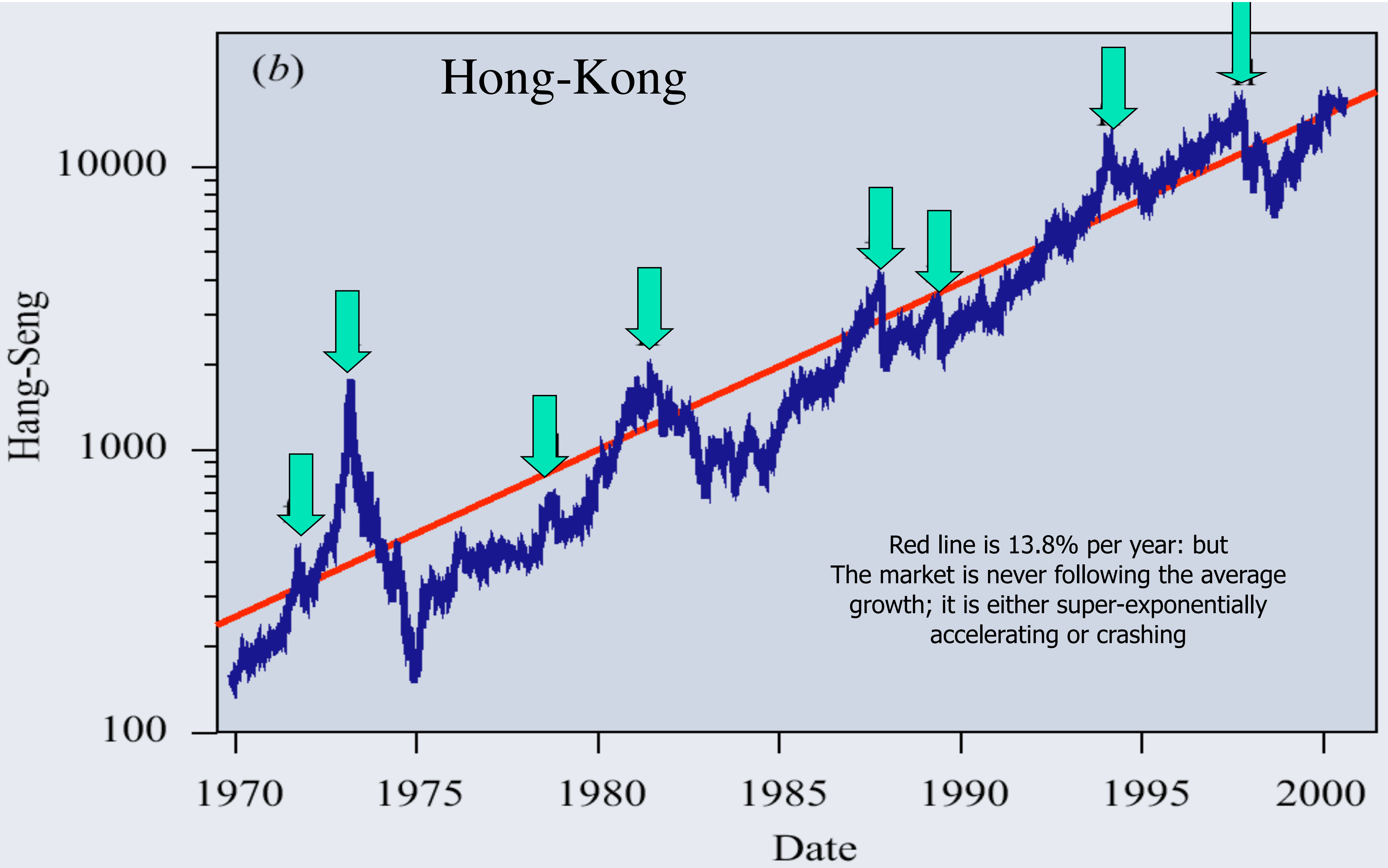
Various Bubbles and Crashes

Each bubble has been rescaled vertically and translated to end at the time of the crash

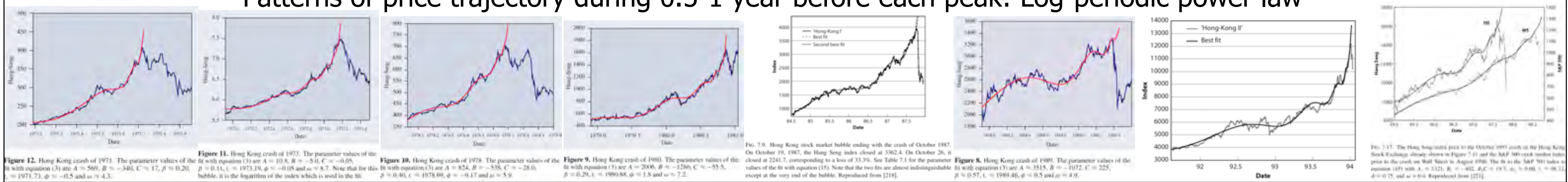




Textbook example of a series of superexponential acceleration followed by crashes
Arrows show peaks followed by corrections of more than 15% in less than three weeks
Hang-Seng
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1970
1975
1980
1985
1990
1995
2000
Date



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



Complex Systems

-positive feedbacks

-non sustainable regimes

-rupture

Thomas Robert Malthus (1766–1834)

1798

autocatalitic proliferation: $\frac{dx}{dt} = a \cdot x$

with a =birth rate - death rate

exponential solution: $X(t) = X(0)e^{a\,t}$

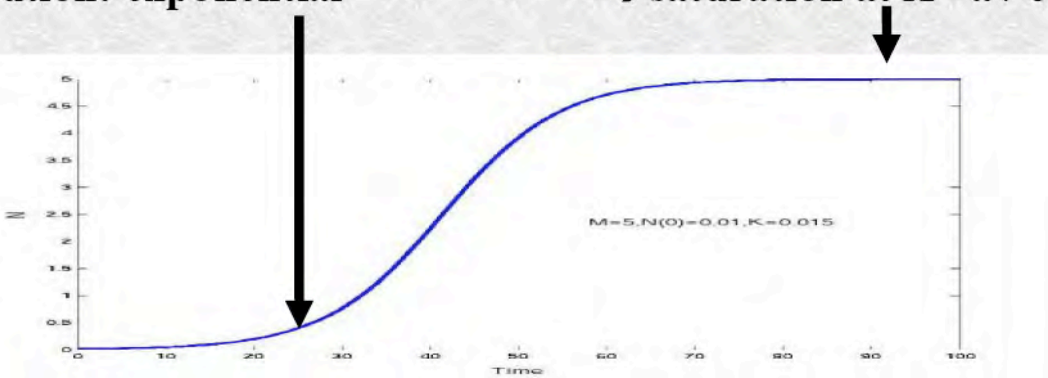
contemporary estimations= doubling of the population every 30yrs

Pierre François Verhulst (1804-1849)

way out exponential explosion:

$dX/dt = a\,X - c\,X^2$ **1838**

Solution: exponential ==========→saturation at X= a / c



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

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 $\rightarrow$ chaos **but** here FTS blow-up.

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

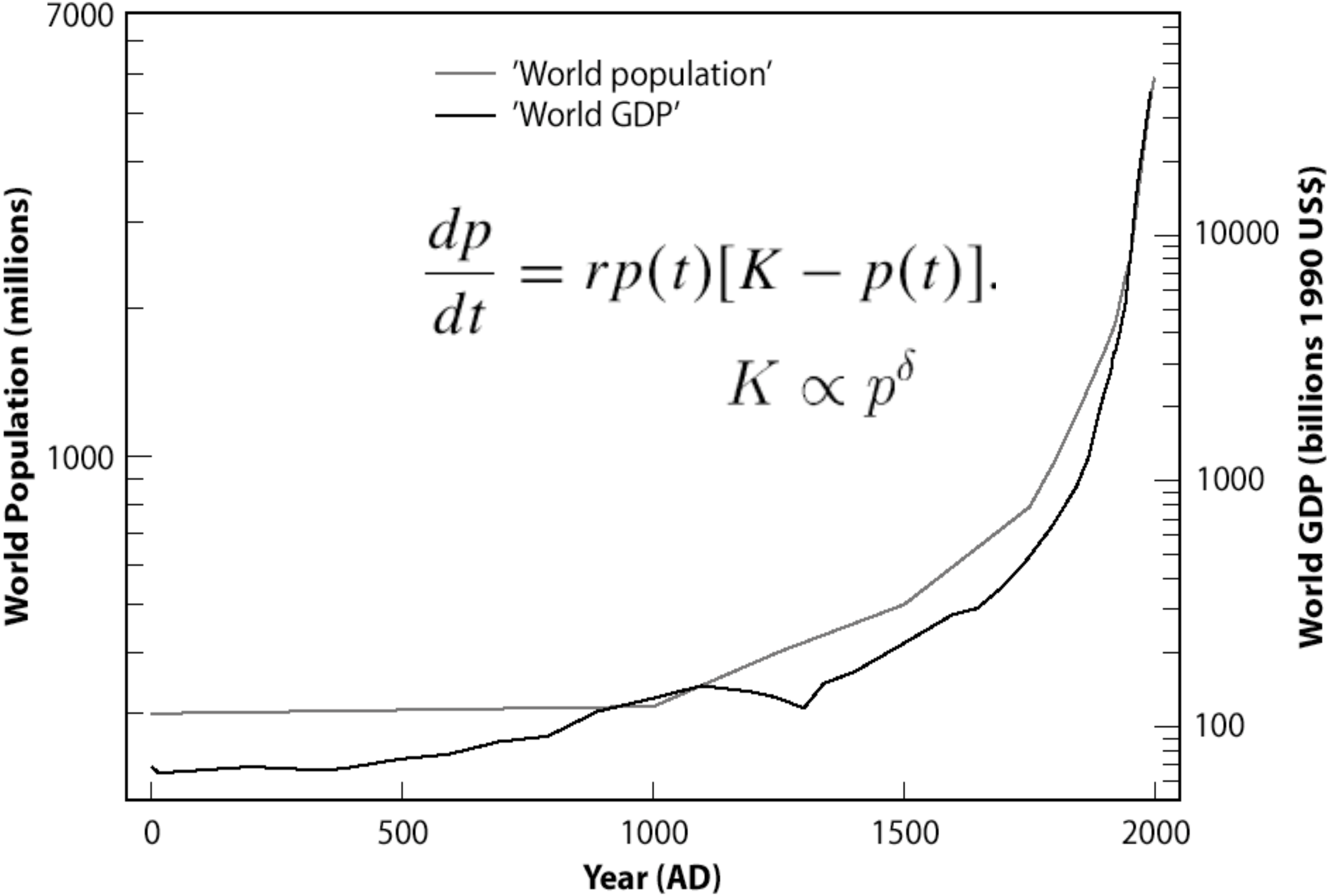
$$\frac{dp}{dt} = r[p(t)]^{1+\delta}$$

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



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

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

Faster than exponential growth

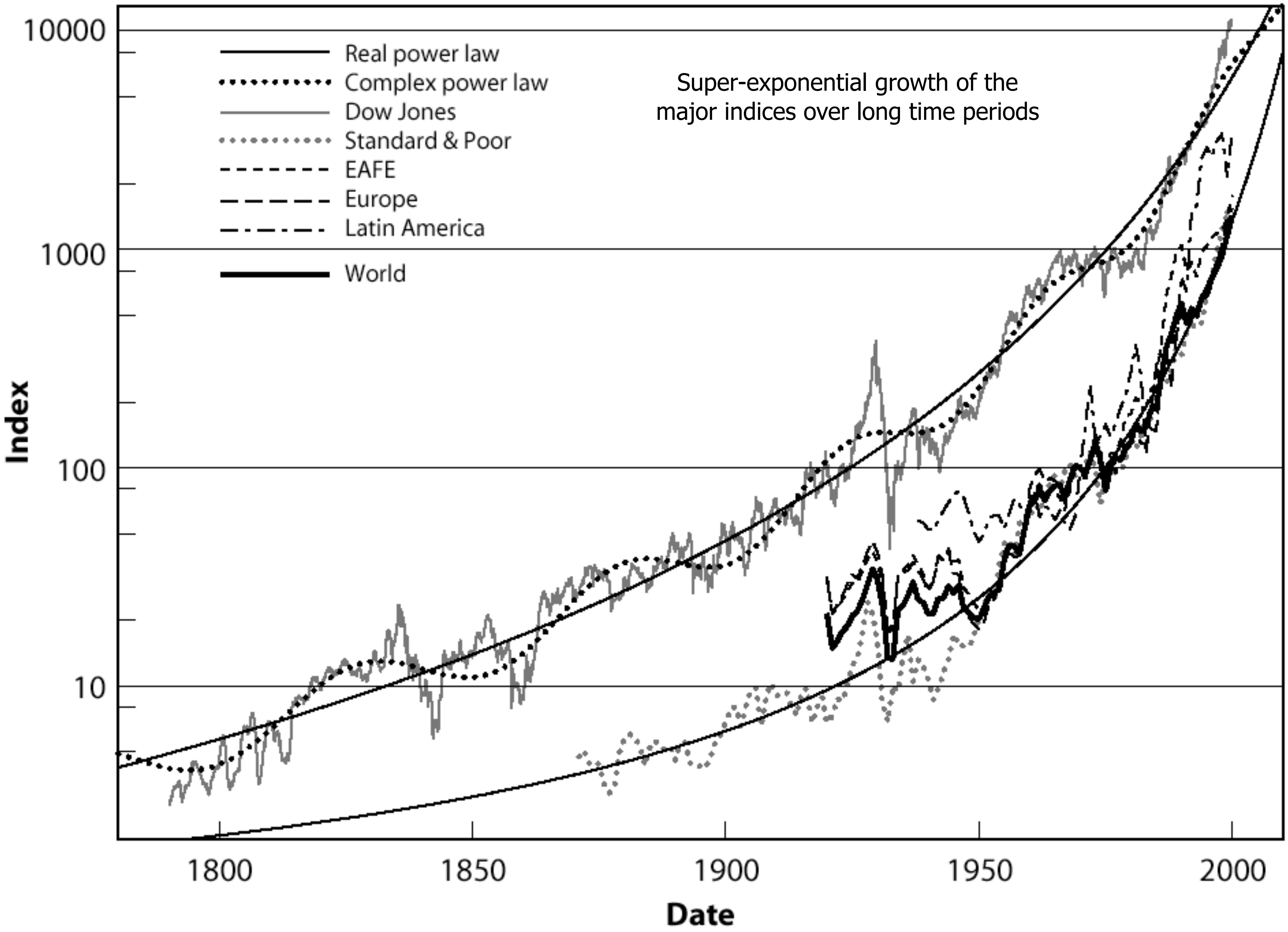
Suppose GROWTH RATE doubles when POPULATION doubles

POPULATION	GROWTH RATE	DOUBLING TIME
1000	1%	69y
2000	2%	69/2y
4000	4%	69/4y
…	…	…
2^n x 1000	2^n %	$69/2^n$ y

Population diverges in finite time

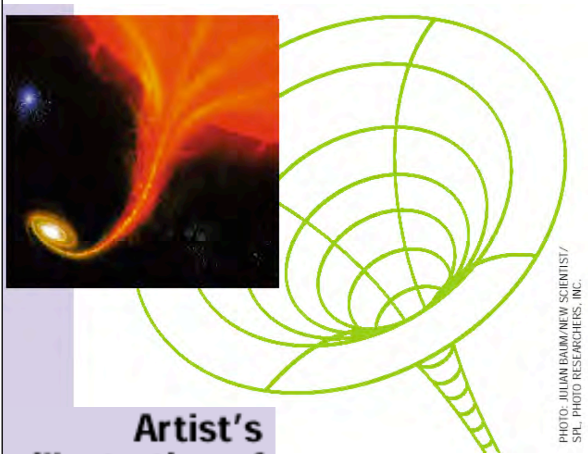
69+69/2+69/4+69/8…=69x(1+1/2+1/4+1/8+…)=69x2=138y

Zeno paradox


10000
1000
100
10
Index
1800
1850
1900
1950
2000
Date
Real power law
Complex power law
Dow Jones
Standard & Poor
EAFE
Europe
Latin America
World
Super-exponential growth of the
major indices over long time periods

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...



Artist's illustration of matter from a red giant star being pulled toward a black hole.

PHOTO: JULIAN BAUM/NEW SCIENTIST/ SPL, PHOTO RESEARCHERS, INC.

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)


THIS WAY TO THE
Bull Market!
Almost there. . . 300 feet. . . Don't Miss The Fun!
I'm a trader.
Hey this Koolaid tastes great!
Must own Yahoo.
Stoopid bears.
Don't be negative.
Take a deep breath!
I'm flying mommy!
El Cliffo

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

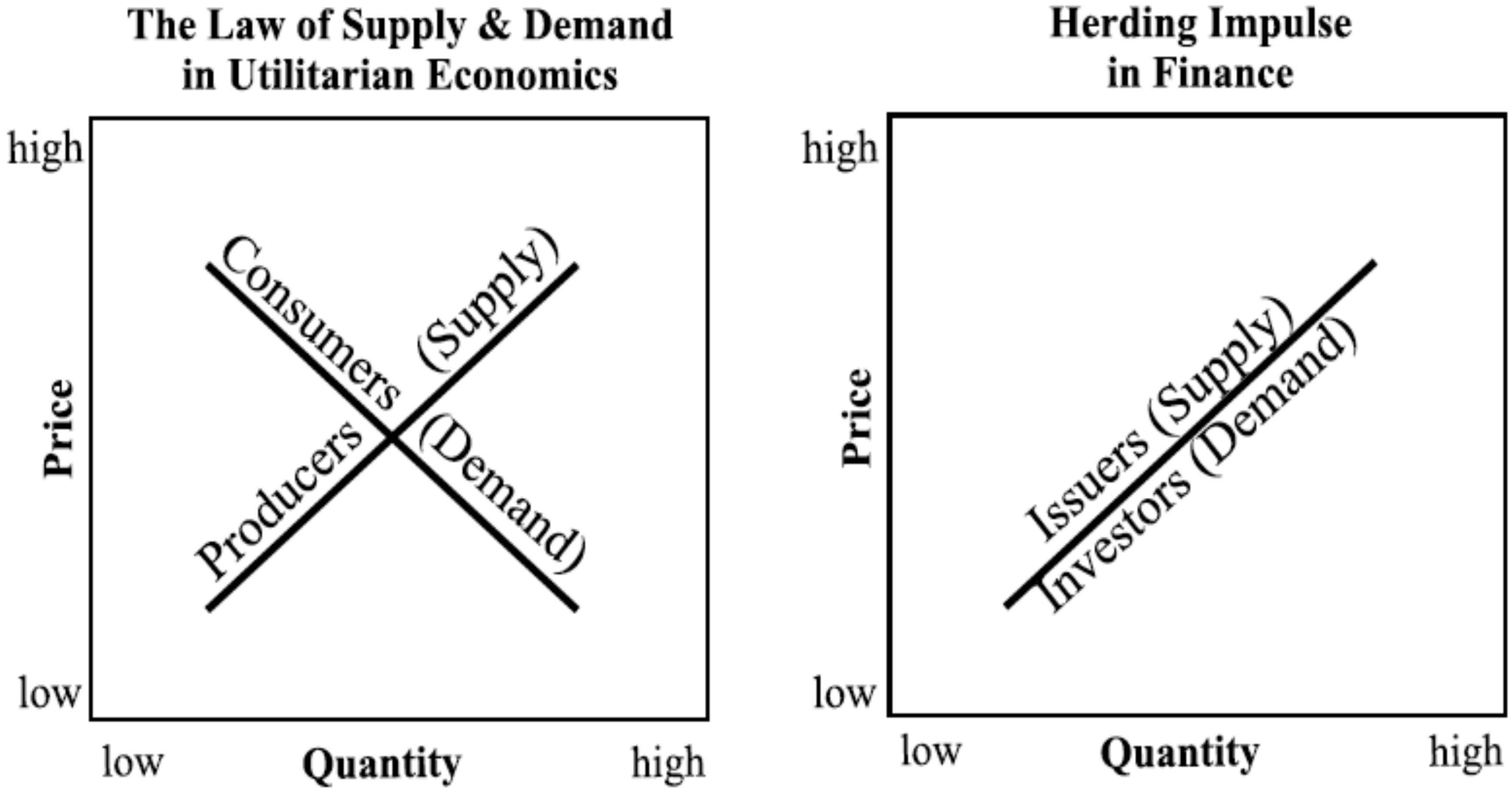
HARRISON HONG, JEFFREY D. KUBIK, and JEREMY C. STEIN*

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.

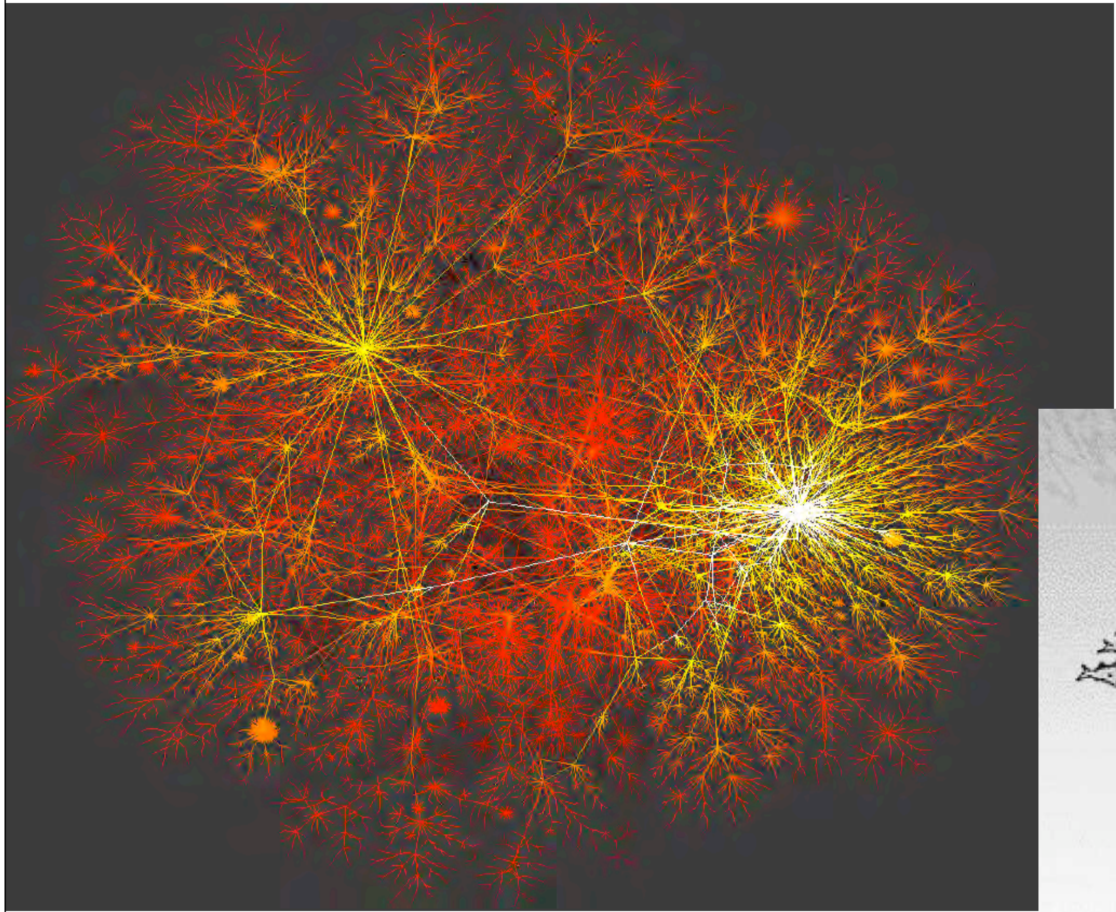
THE JOURNAL OF FINANCE • VOL. LX, NO. 6 • DECEMBER 2005

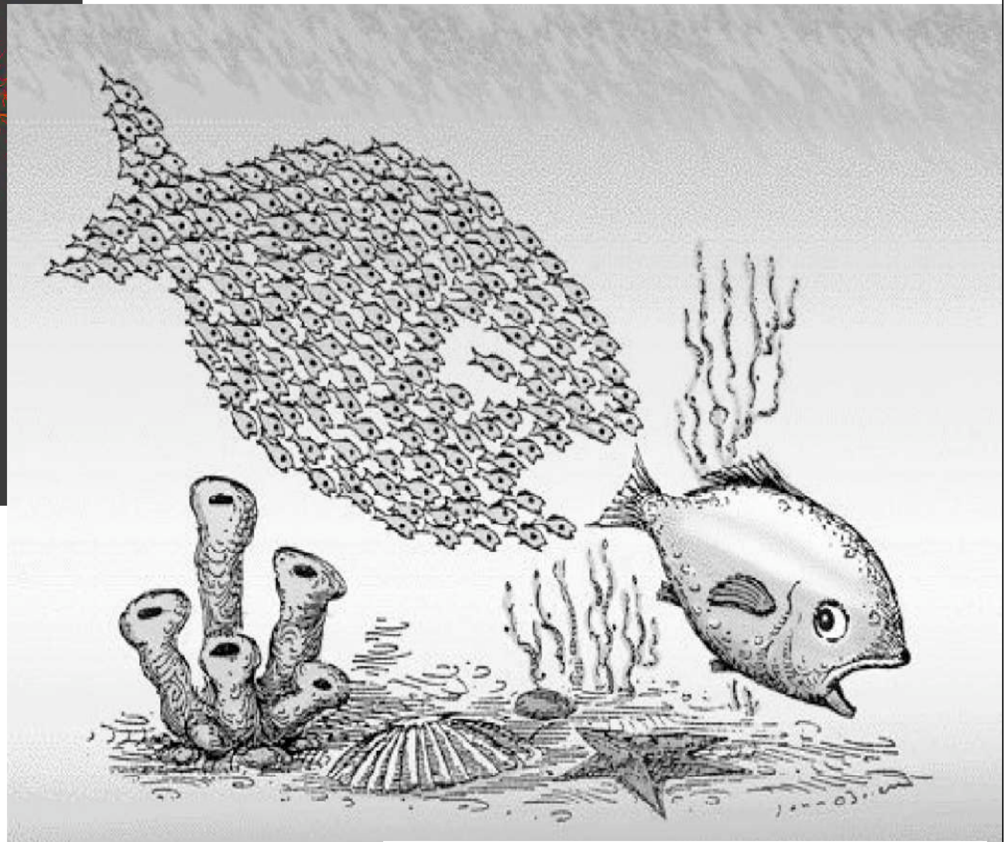
A fundamental observation about human society is that people who communicate regularly with one another think similarly. There is at any place and in any time a *Zeitgeist*, a spirit of the times. . . . Word-of-mouth transmission of ideas appears to be an important contributor to day-to-day or hour-to-hour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

Shiller (2000)


The Law of Supply & Demand
in Utilitarian Economics
high
low
Price
Consumers (Demand)
Producers (Supply)
low
Quantity
high
Herding Impulse
in Finance
high
low
Price
Issuers (Supply)
Investors (Demand)
low
Quantity
high

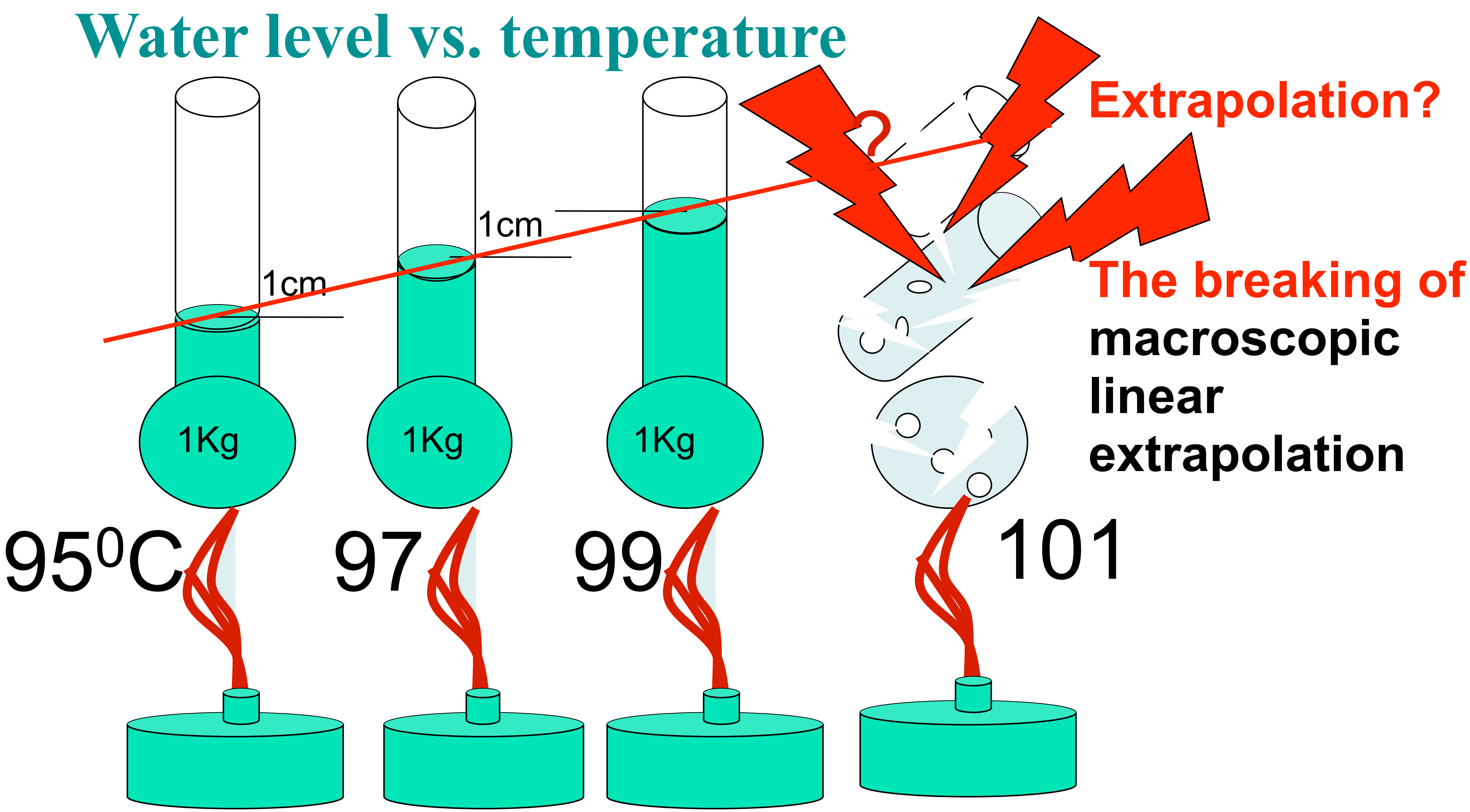
Network effects and Collective behavior





Courtesy of B. A. Huberman.

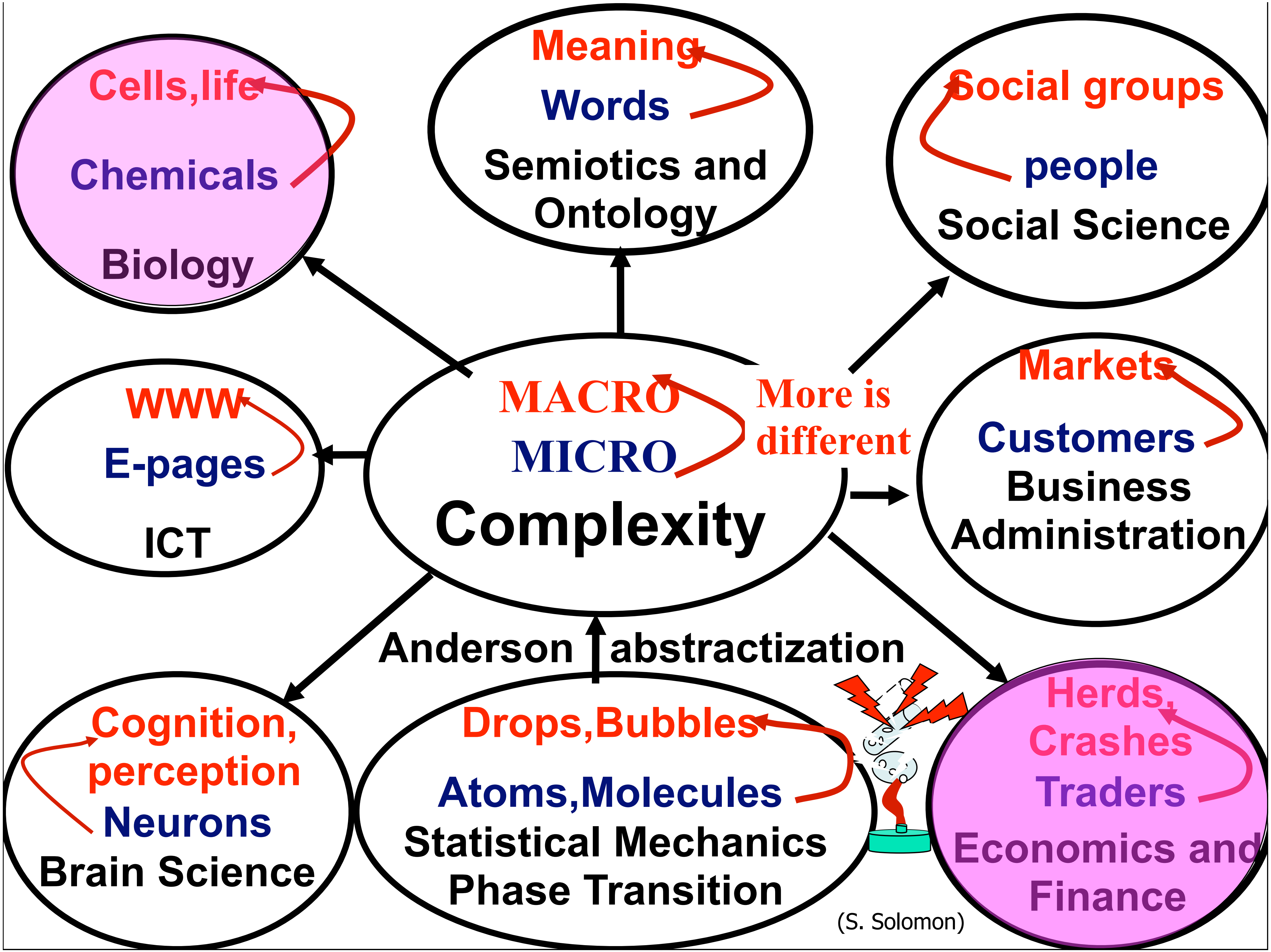
Simplest Example of a "More is Different" Transition



BOILING PHASE TRANSITION

More is different: a single molecule does not boil at $100C^0$

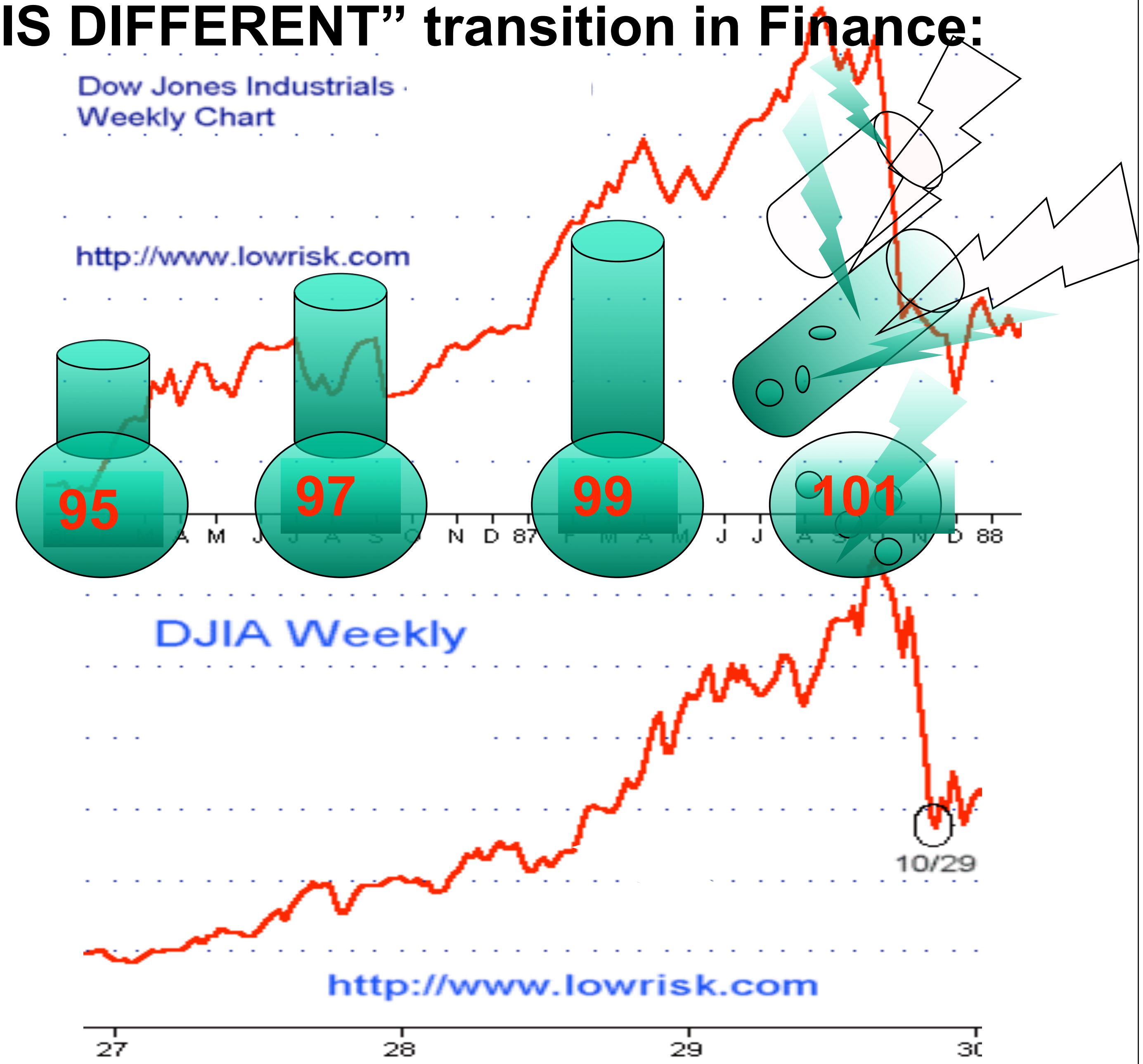
(S. Solomon)


Cells,life
Chemicals
Biology
Meaning
Words
Semiotics and Ontology
Social groups
people
Social Science
WWW
E-pages
ICT
MACRO
MICRO
More is different
Complexity
Markets
Customers
Business Administration
Anderson
abstractization
Cognition, perception
Neurons
Brain Science
Drops,Bubbles
Atoms,Molecules
Statistical Mechanics
Phase Transition
Herds, Crashes
Traders
Economics and Finance
(S. Solomon)

Example of "MORE IS DIFFERENT" transition in Finance:

Instead of Water Level:

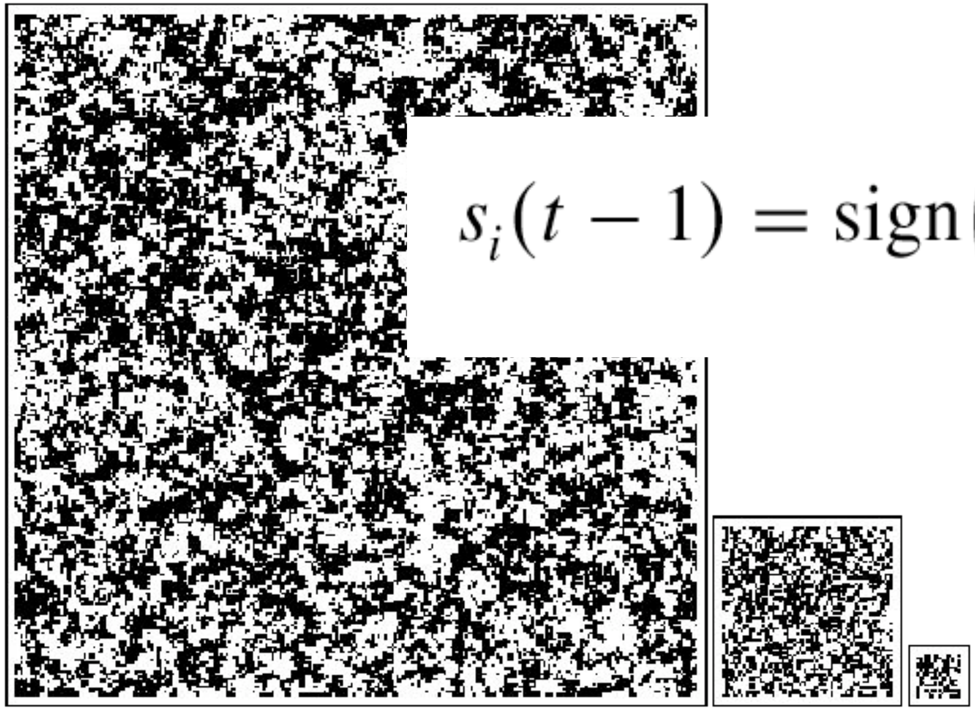
-economic index (Dow-Jones etc…)

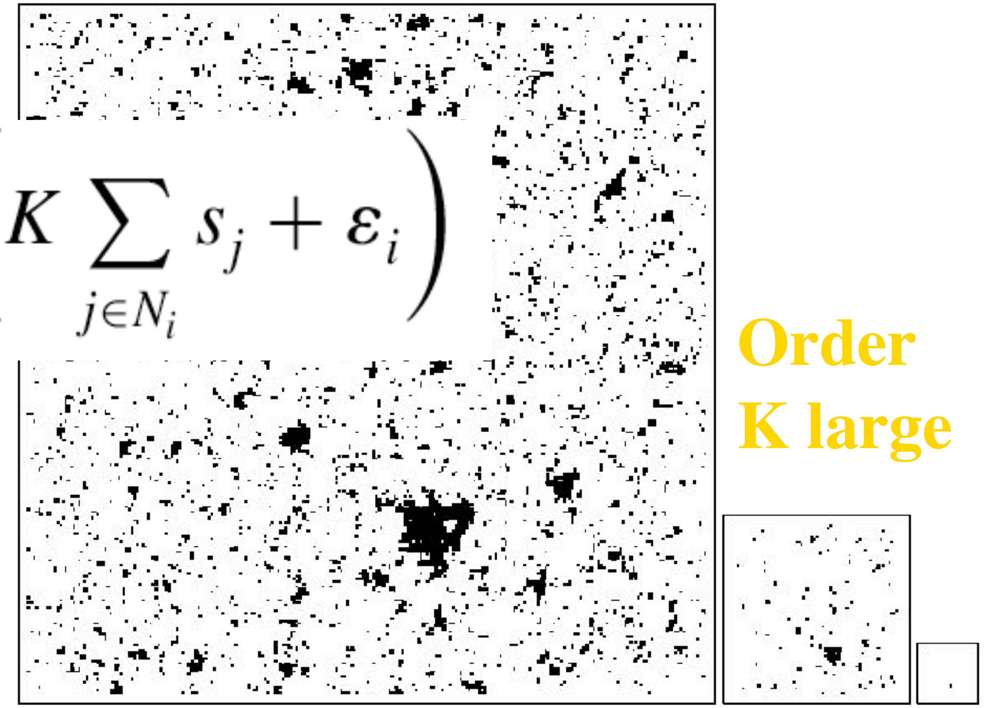


Crash = result of collective behavior of individual traders

(S. Solomon)

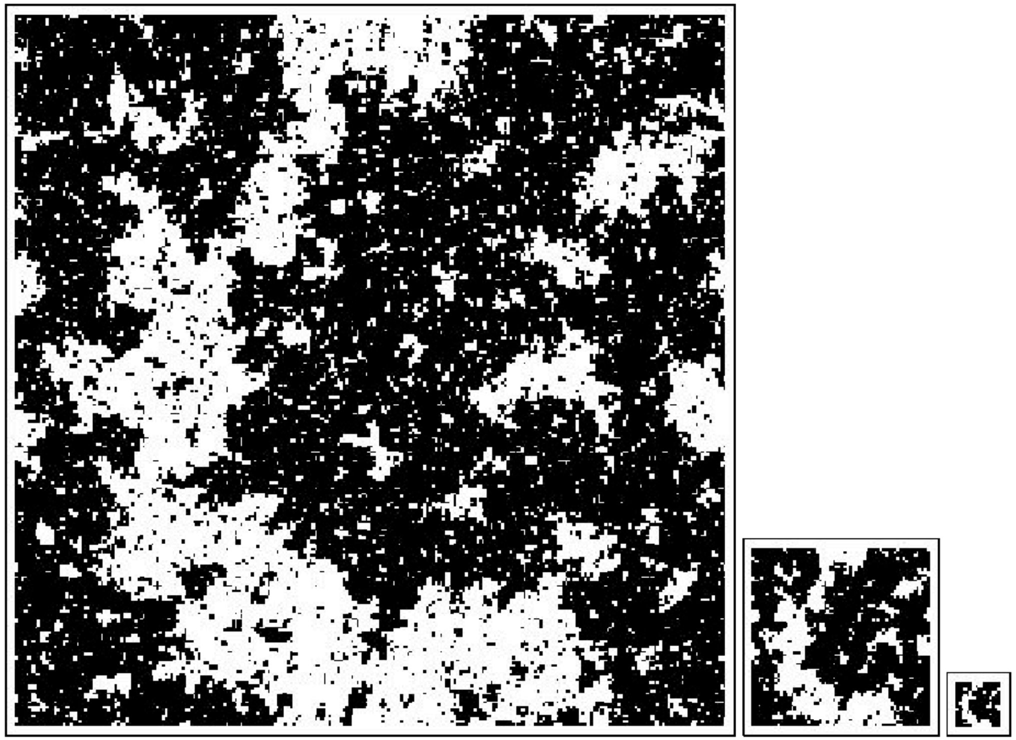
$$s_i(t-1) = \mathrm{sign}\left(K \sum_{j \in N_i} s_j + \varepsilon_i\right)$$





Order
K large

Disorder : K small



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. **β<0: rational agents**

- **β>0: over-confident agents**

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

Price clearing condition

If $info_i(t) > info_{threshold}i$: $s_i(t) = +1$

$$a_i(t) = 0.02 \cdot cash_i(t\text{-}1) \,/\, price(t\text{-}1)$$

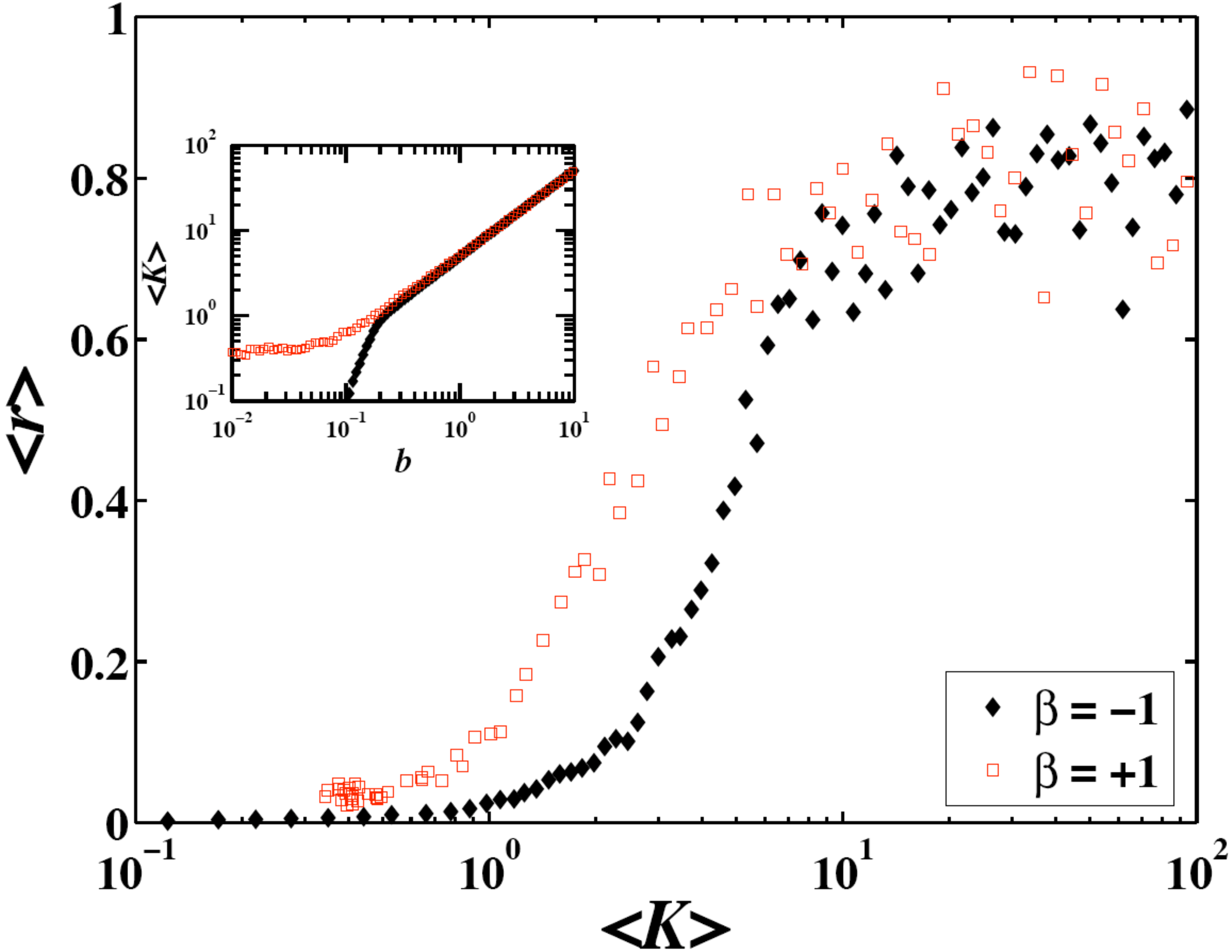
If $info_i(t) < info_{threshold}i$: $s_i(t) = -1$

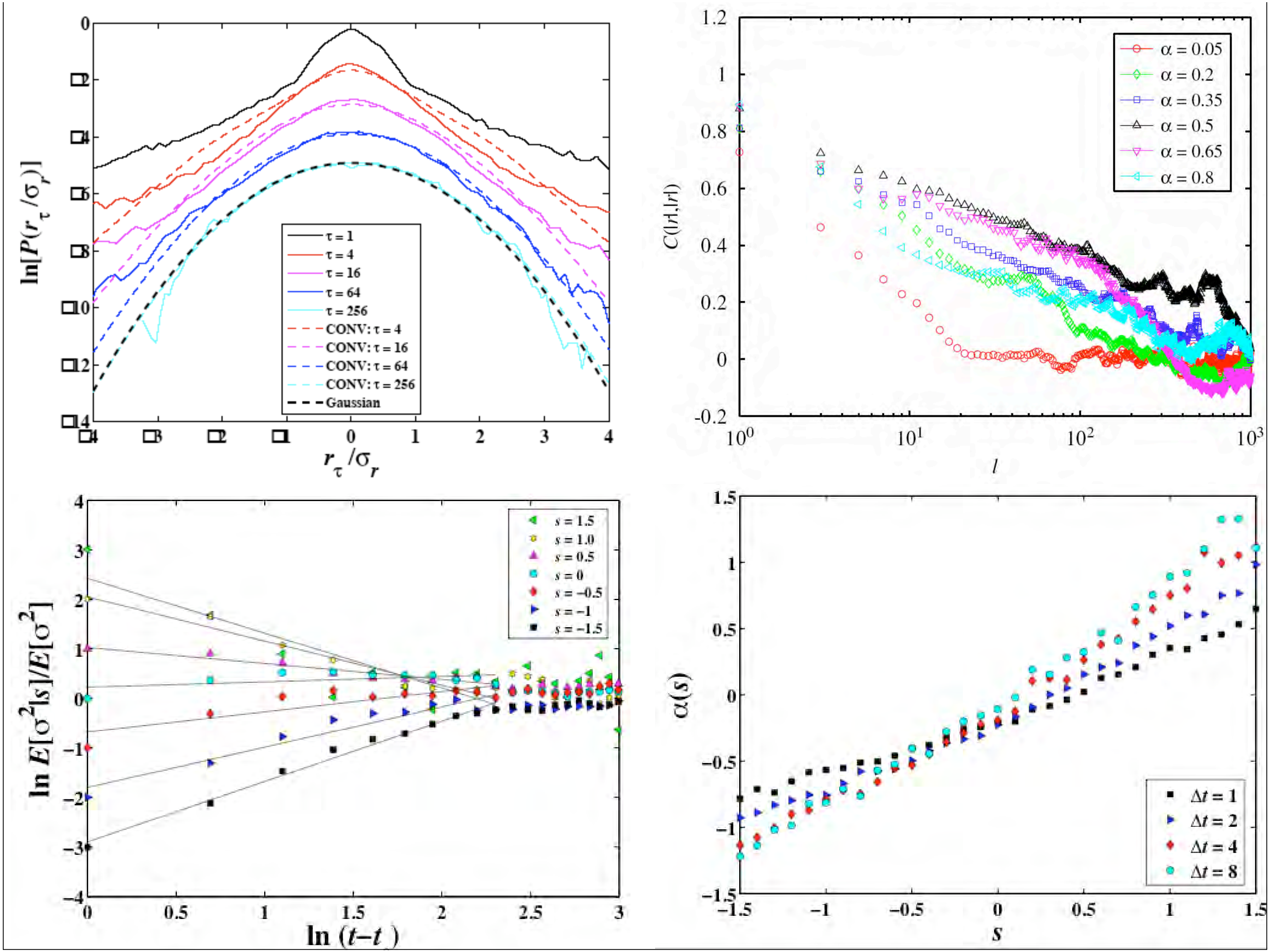
$$a_i(t) = 0.02 \cdot stocks_i(t\text{-}1)$$

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

$$\log(price(t)) = \log(price(t-1)) + r(t)$$

Illustration of the existence of an Ising-like phase transition,
as a function of the control parameter b_{max} for both regimes β = -1 and β=1

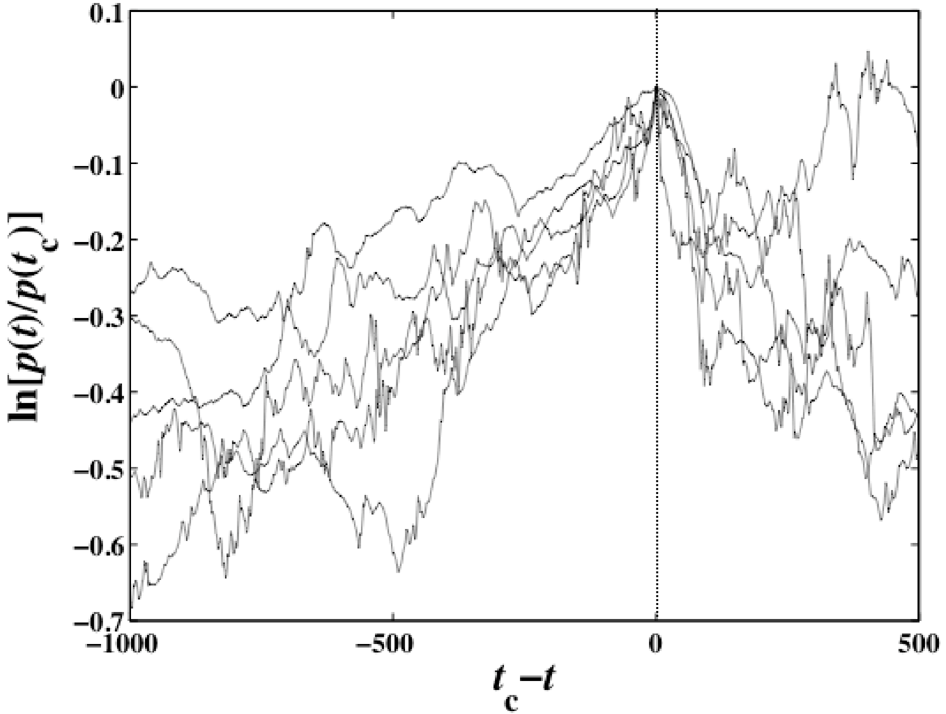




ln[P(r_τ /σ_r)]
r_τ /σ_r
τ = 1
τ = 4
τ = 16
τ = 64
τ = 256
CONV: τ = 4
CONV: τ = 16
CONV: τ = 64
CONV: τ = 256
Gaussian
C(|r|,|r|)
l
α = 0.05
α = 0.2
α = 0.35
α = 0.5
α = 0.65
α = 0.8
ln E[σ²|s]/E[σ²]
ln (t−t)
s = 1.5
s = 1.0
s = 0.5
s = 0
s = −0.5
s = −1
s = −1.5
α(s)
s
Δt = 1
Δt = 2
Δt = 4
Δt = 8

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 $t = 0$.



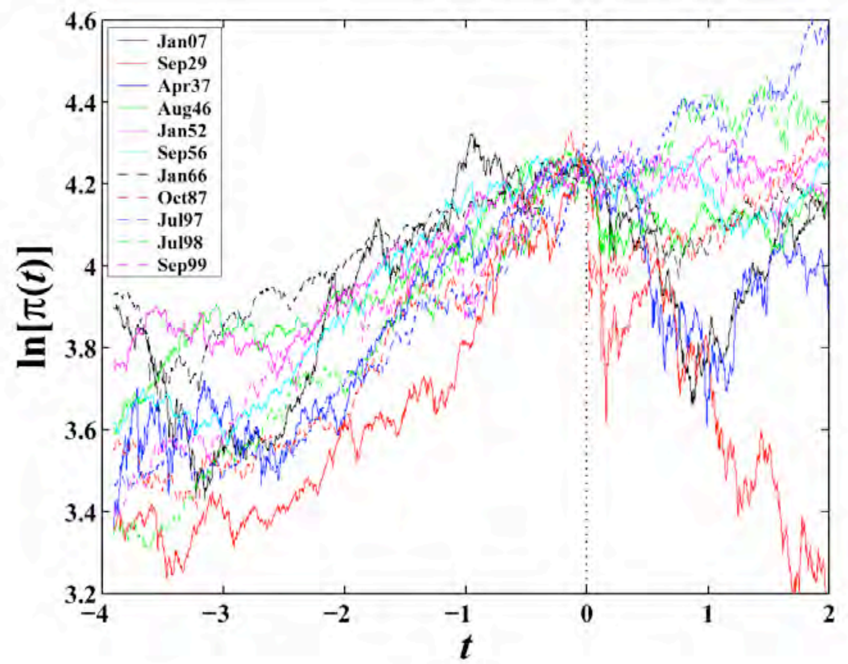


Figure 4: (Color online) Superposed epoch analysis of the 11 time intervals, each of 6 years long, of the DJIA index centered on the time of the maxima of the 11 predictor peaks above $AI = 0.3$ of the alarm index shown in Fig. 3.

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

Aggregation of information

The aggregated information of agent *i* is:

$$info_i(t) = c_{1i} \cdot \sum_{j=1}^{J} k_{ij} E_i[s_j(t)] + c_{2i} \cdot u(t) \cdot news(t) + c_{3i} \cdot \epsilon_i(t)$$

imitation term — news term — idiosyncratic term

$$c_{1/2/3} \sim UD \in [0, c_{1/2/3\,max}]$$

personal susceptibility to the different sources of information

$$\epsilon_i \sim N(0,1)$$

Gaussian noise

$$news(t) \sim N(0,1)$$

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

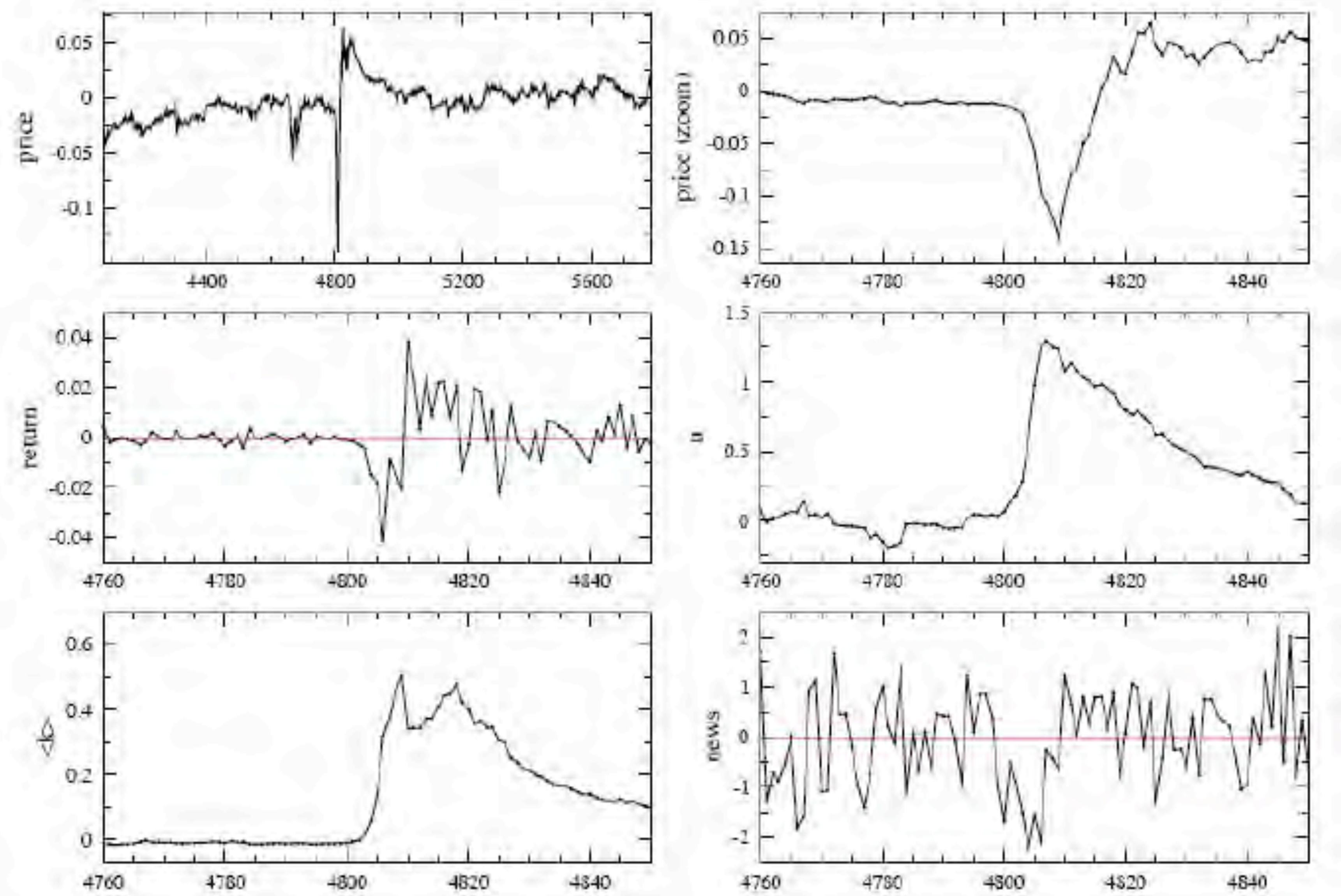
past neighbour j performance

$$u(t) = \alpha \cdot u(t-1) + r(t-1) \cdot news(t-2) \cdot \frac{1-\alpha}{\sigma_r}$$

past news performance

G. Harras and D. Sornette, Endogenous versus exogenous origins of financial rallies and crashes in an agent-based model with Bayesian learning and imitation, J. Economic Behavior and Organization (2008) (http://arXiv.org/abs/0806.2989

News impact



Impact of the news to some values, generated with $C_1 = C_2 = C_3 = 1.0$.

FOUR EXAMPLES

(i) the fluctuation-susceptibility theorem transforms into a remarkable classification of financial volatility shocks (endogenous versus exogenous),

(ii) the Ising model of phase transitions can be generalized to model the stylized facts of financial markets,

(iii) the concepts of collective phenomena and phase transitions (with spontaneous symmetry breaking) help understand financial bubbles and their following crashes,

(iv) the mathematics of quantum physics provides a new quantum decision theory solving the known paradoxes.

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

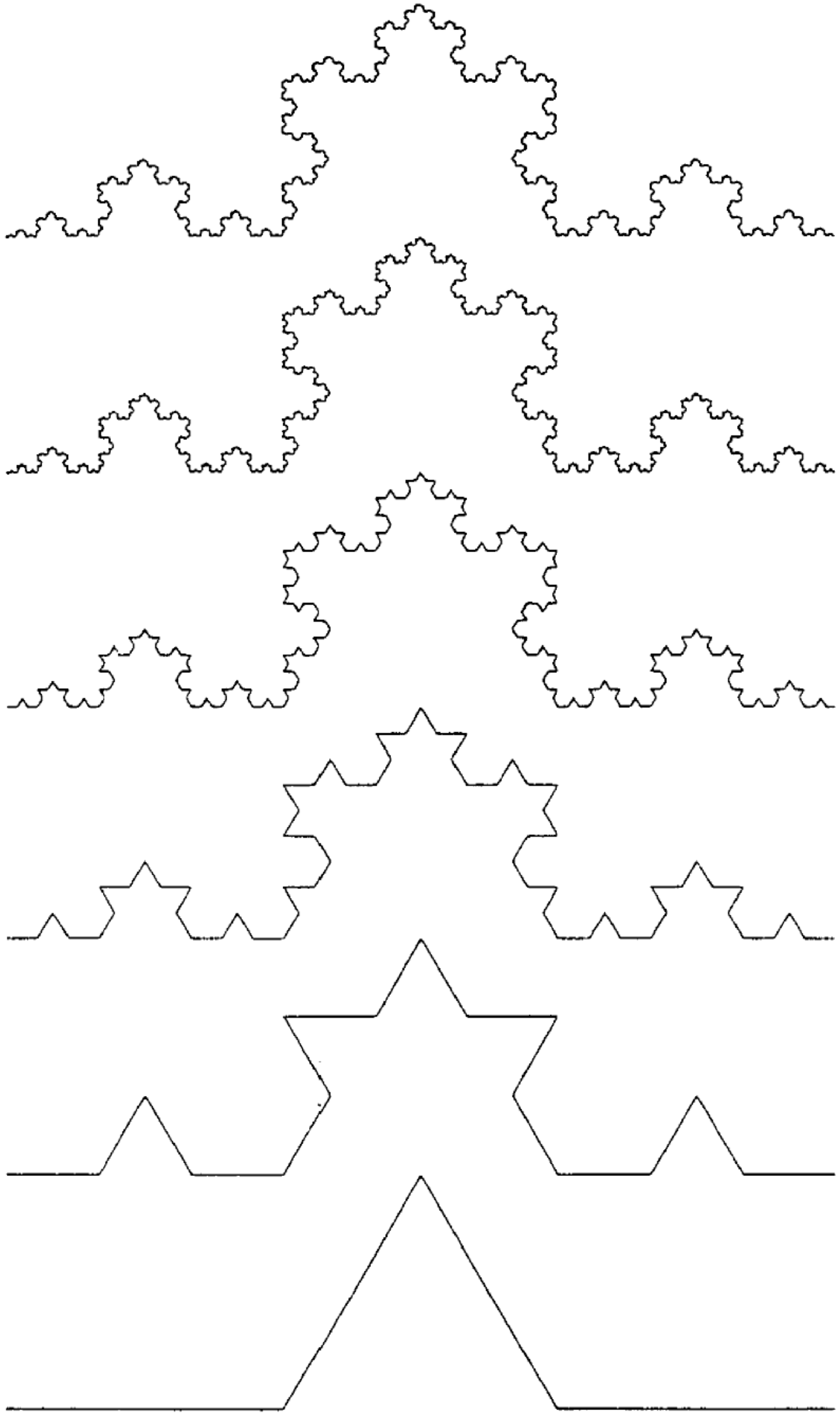
  Log-periodicity

FRACTALS

1) $d \in N$ Euclid (ca. 325-270 BC)

2) $d \in R$ Mandelbrot (1960-1980)
(Weierstrass, Hausdorff, Holder, …)

3) $d \in C$

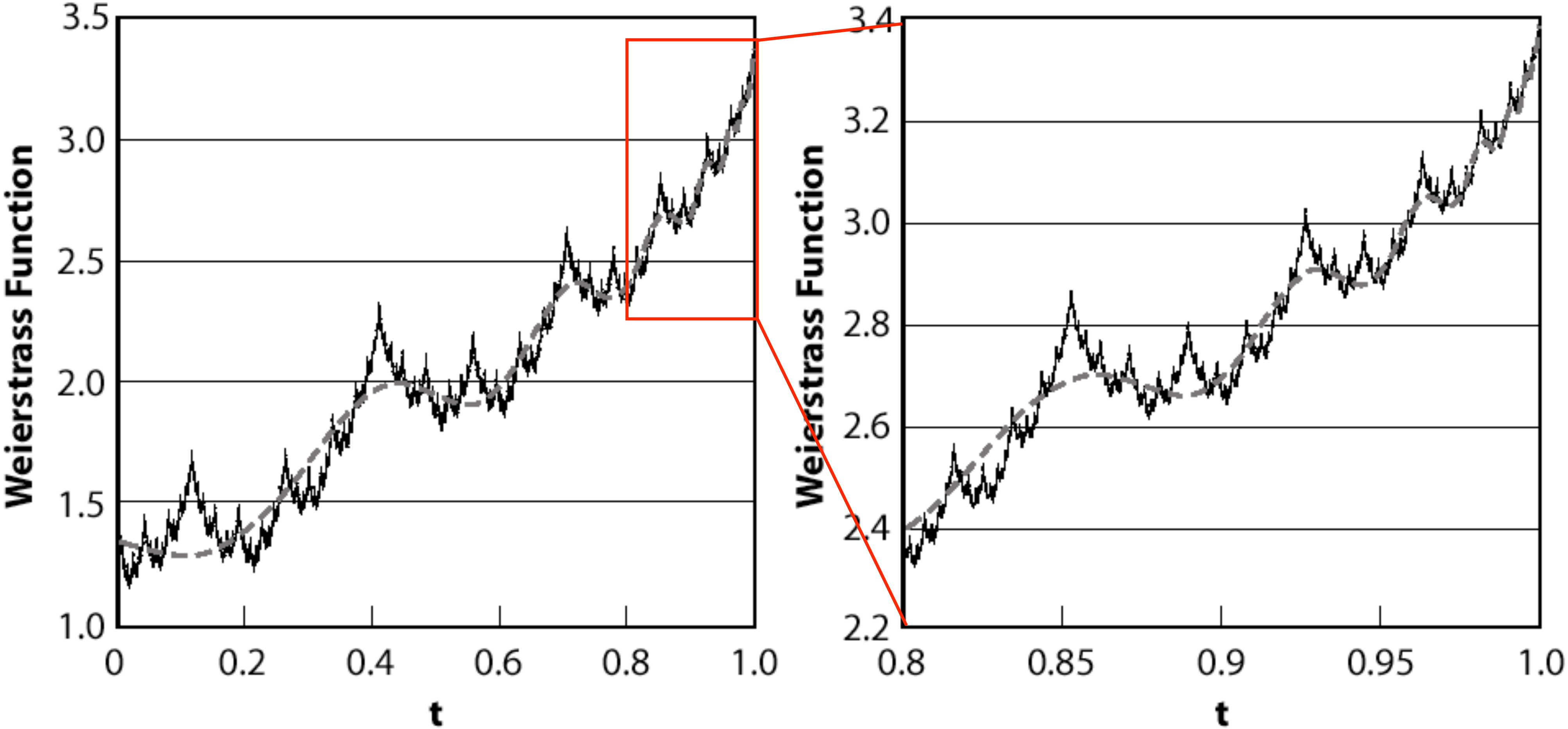


Discrete scale invariance
Complex fractal dimension
Log-periodicity

Prefered scaling ratio is 3

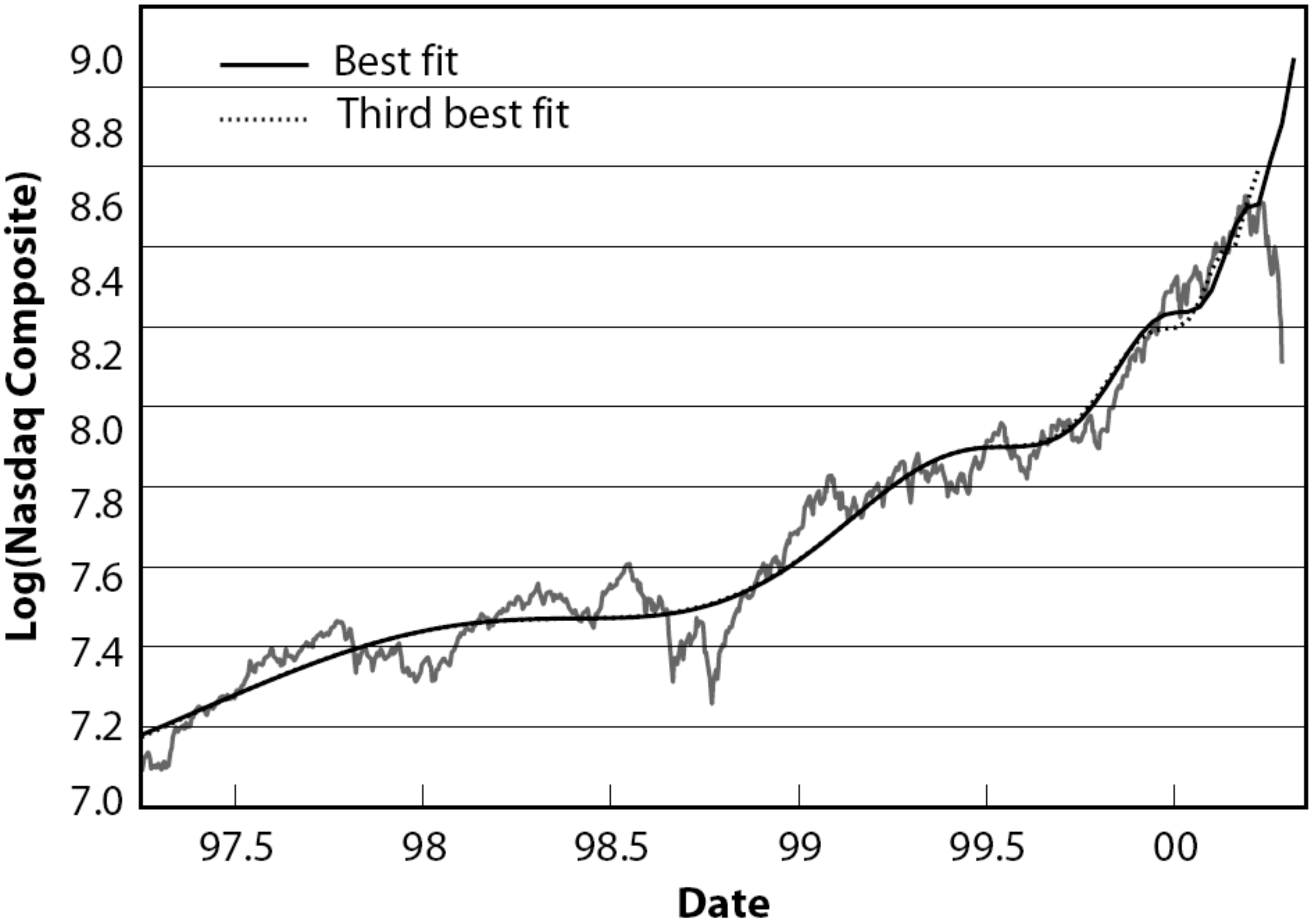
$$D(n) = \ln 4/\ln 3 + i\, 2\pi n/\ln 3$$

Fractal function
(Weierstrass)



THE NASDAQ CRASH OF APRIL 2000

"New Economy": ICT



Real-estate in the UK

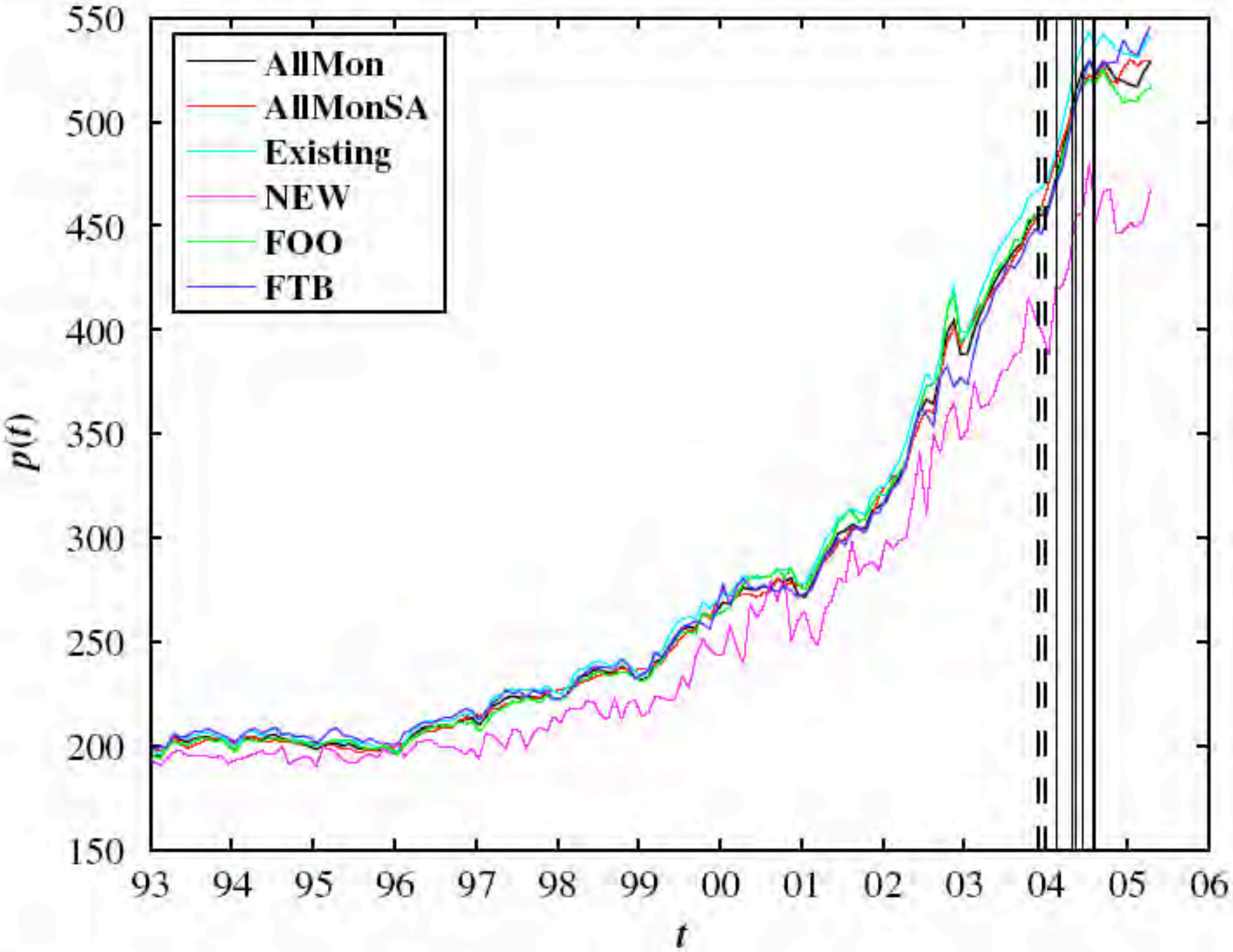


Fig. 1. (Color online) Plot of the UK Halifax house price indices from 1993 to April 2005 (the latest available quote at the time of writing). The two groups of vertical lines correspond to the two predicted turning points reported in Tables 2 and 3 of [1]: end of 2003 and mid-2004. The former (resp.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

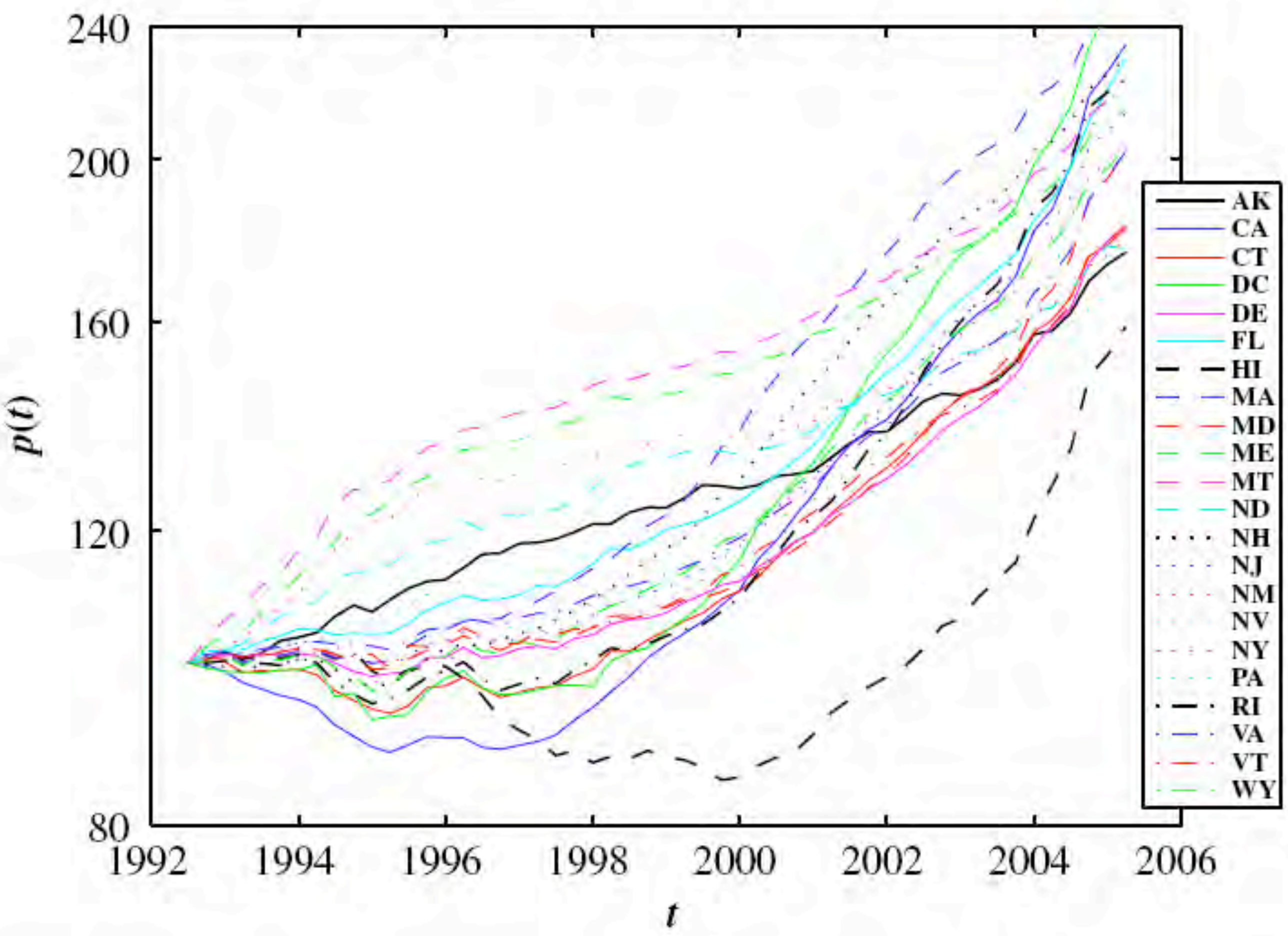
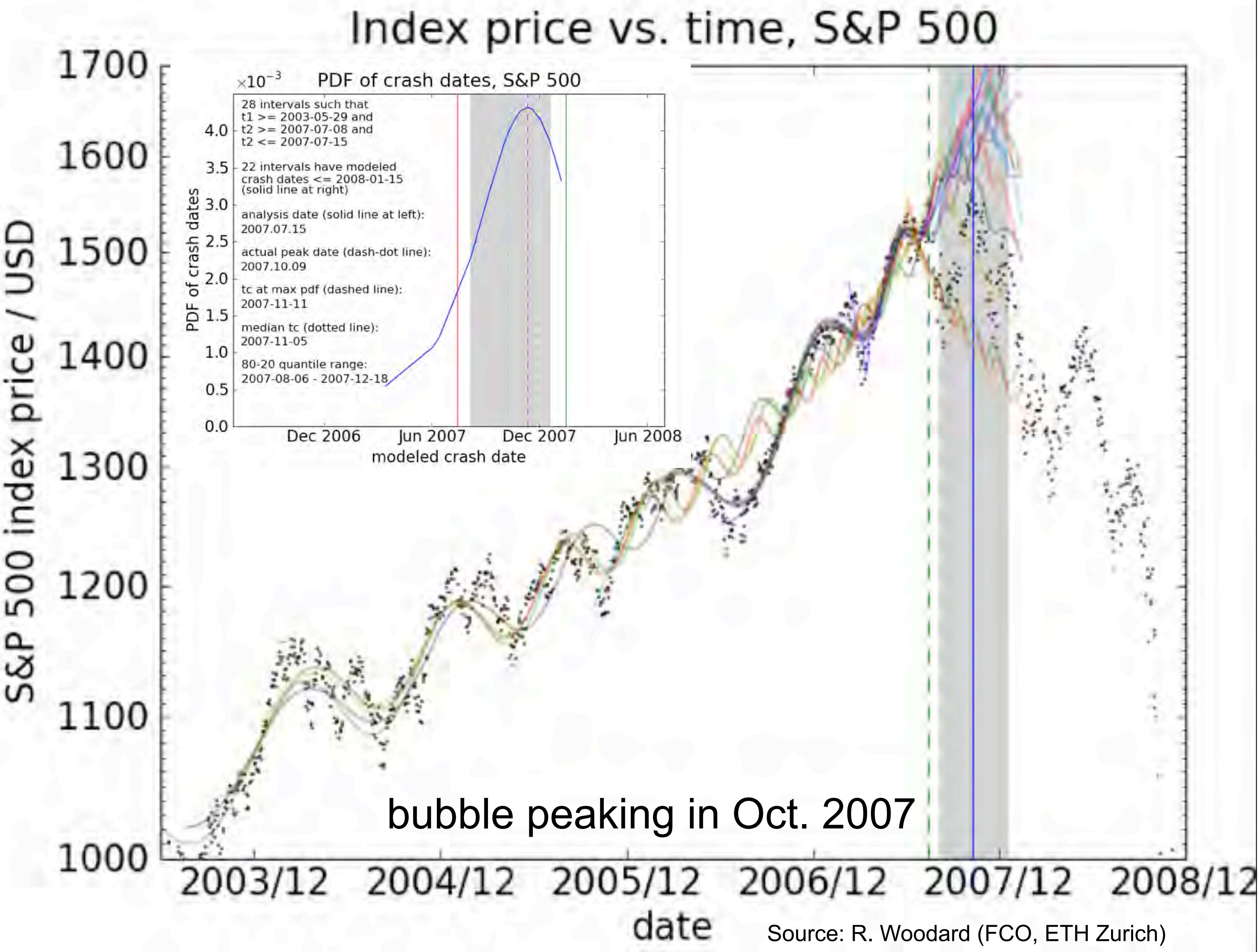


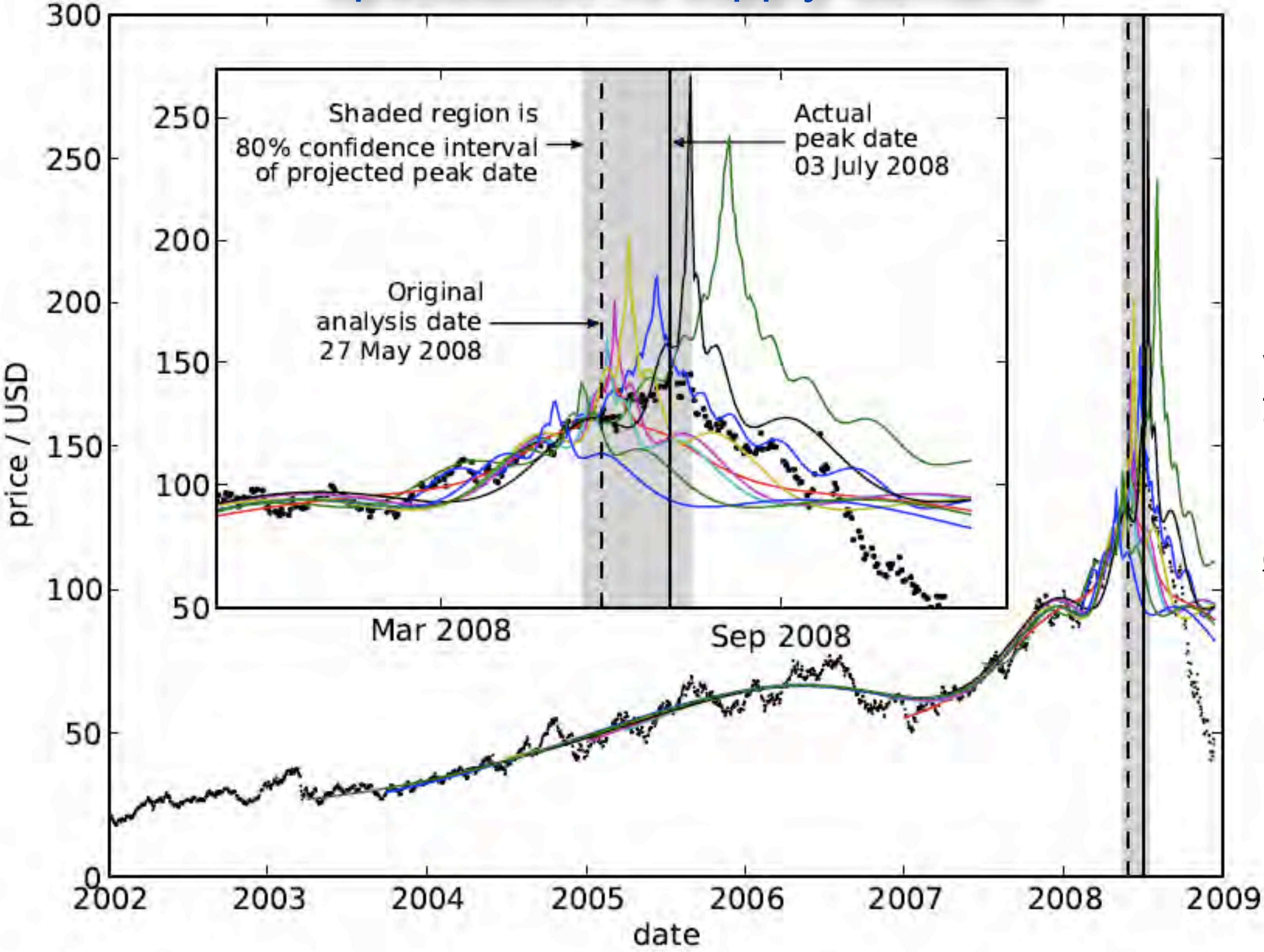
Fig. 5. (Color online) Quarterly average HPI in the 21 states and in the District of Columbia (DC) exhibiting a clear upward faster-than-exponential growth. For better representation, we have normalized the house price indices for the second quarter of 1992 to 100 in all 22 cases. The corresponding states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

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



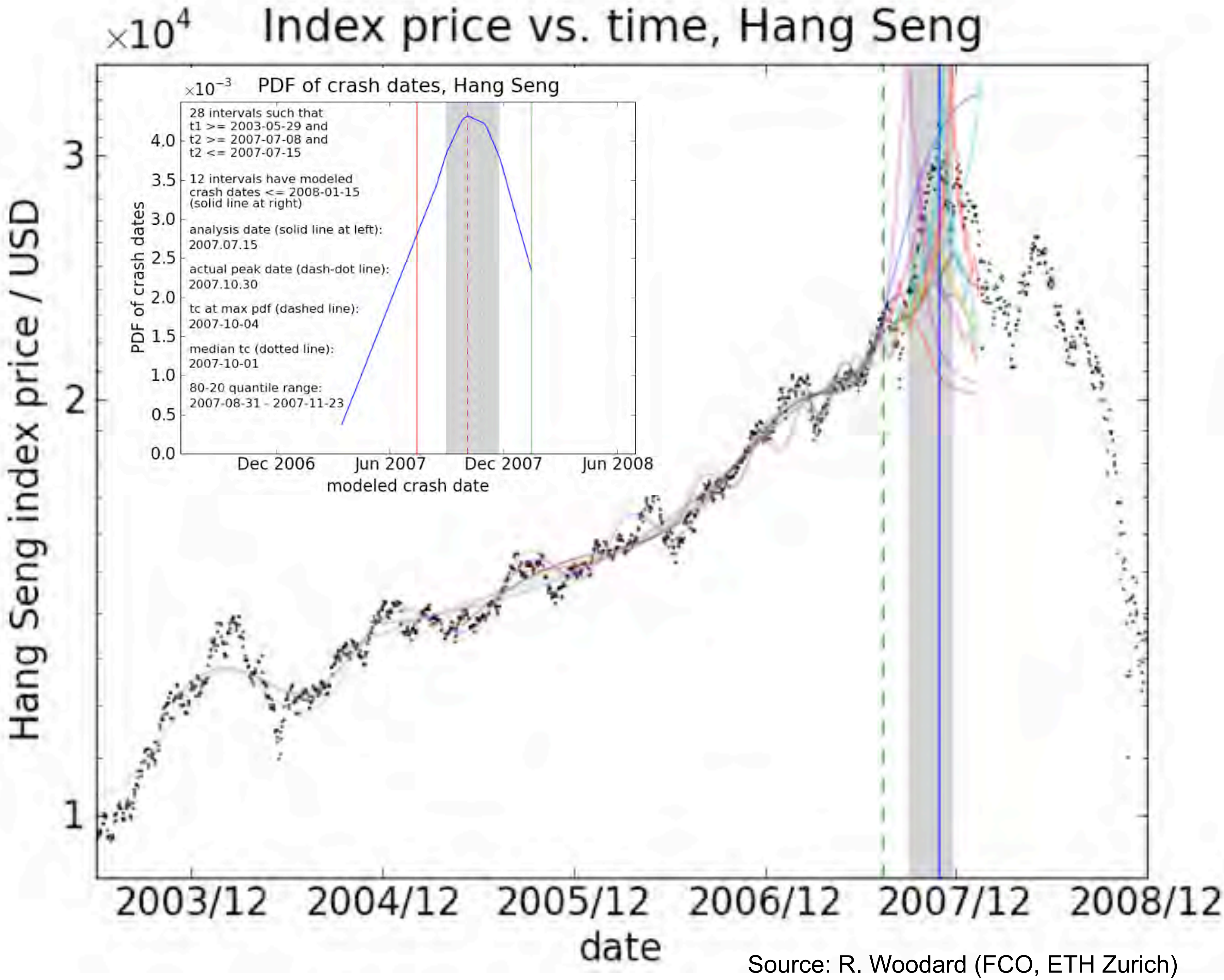
Source: R. Woodard (FCO, ETH Zurich)

2006-2008 Oil bubble
Speculation vs supply-demand

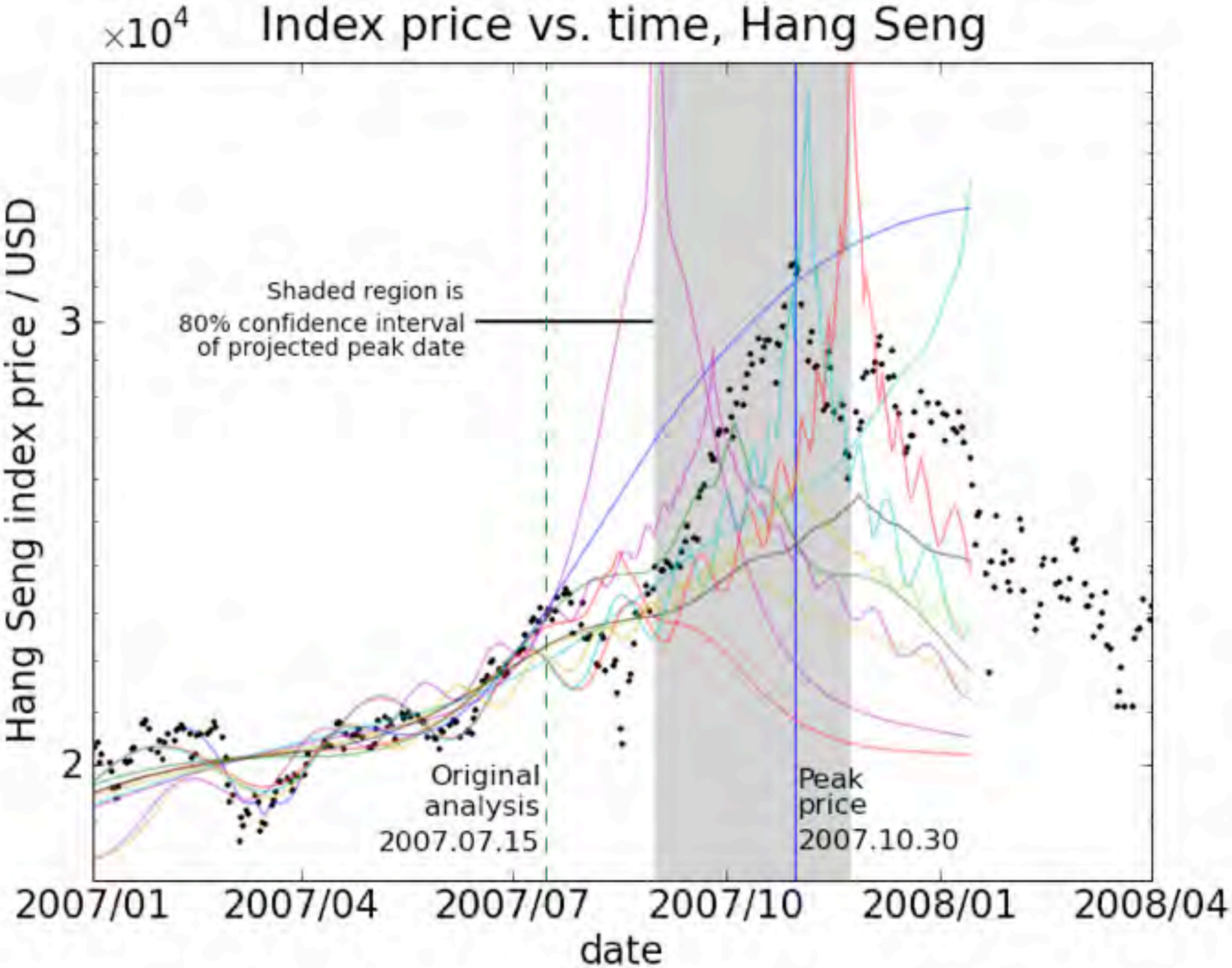


D. Sornette, R. Woodard and W.-X. Zhou, The 2006-2008 Oil Bubble and Beyond, Physica A 388, 1571-1576 (2009) (arXiv.org/abs/0806.1170)

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.



Source: R. Woodard (FCO, ETH Zurich)



Source: R. Woodard (FCO, ETH Zurich)

FOUR EXAMPLES

(i) the fluctuation-susceptibility theorem transforms into a remarkable classification of financial volatility shocks (endogenous versus exogenous),

(ii) the Ising model of phase transitions can be generalized to model the stylized facts of financial markets,

(iii) the concepts of collective phenomena and phase transitions (with spontaneous symmetry breaking) help understand financial bubbles and their following crashes,

(iv) the mathematics of quantum physics provides a new quantum decision theory solving the known paradoxes.

1. Classical Decision Theory

1.1. Notations and definitions
1.2. Typical paradoxes
1.3. Absence of solution

2. Quantum Decision Theory

2.1. Definitions and axioms
2.2. General properties
2.3. Solution of paradoxes

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)

Save utility theory ?

Non-expected utility functionals.

For a lottery $L = \{x_n,\ p(x_n)\}$

Instead of expected utility $U(L)$, utility functionals

$$F(L) = F[x_n,\ p(x_n),\ u(x_n)]$$

Minimal requirements: Risk aversion

Between two lotteries L_1 and L_2, with the same mean

$$\overline{x}(L_1) = \overline{x}(L_2)$$

the lottery L_1 is preferred to L_2 ($L_1 > L_2$) if $\Delta^2(L_1) < \Delta^2(L_2)$.

Then $F(L_1) > F(L_2)$.

Safra and Segal (2008): Non-expected utility functionals do not remove paradoxes!

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!

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.
- Paradoxes of classical decision theory are explained.
- Good quantitative agreement with empirical data.
- Conjunction fallacy is a sufficient condition for disjunction effect.

V.I. Yukalov and D. Sornette (2009)
Quantum Decision Theory, arXiv.org.0802.3597 (2008);
Mathematical Basis of Quantum Decision Theory, ssrn.com/abstract=1263853

A partial lists of achievements of Econophysics

- “universality”
- agent-based models, induction, evolutionary models [1, 9, 11, 21],
- option theory for incomplete markets [4, 6],
- interest rate curves [5, 38],
- minority games [8],
- theory of Zipf law and its economic consequences [12, 13, 27],
- theory of large price fluctuations [14],
- theory of bubbles and crashes [17, 22, 40],
- random matrix theory applied to covariance of returns [20, 36, 37],
- methods and models of dependence between financial assets [25, 43].

G. Daniel and D. Sornette, Econophysics: historical perspectives, in the Encyclopedia of Quantitative Finance, edited by Rama Cont (www.wiley.com/go/eqf), Section: History of Quantitative Modeling (1st section out of 21), edited by Perry Mehrling and Murad Taqqu (http://arXiv.org/abs/0802.1416)

At present: most exciting progresses at the boundary between economics and the biological, cognitive, and behavioral sciences.

Physics has still a role to play as a unifying framework full of concepts and tools to deal with the complex.

The modeling skills of physicists explain their impressive number in investment and financial institutions (data-driven approach coupled with a pragmatic sense of theorizing)

KEY CHALLENGE:

true trans-disciplinarity by “marriage”