CSSS 2011, July 3-4 ISC Paris

COMPLEXITY: FROM NATURAL TO SOCIO-ECONOMIC SCIENCES:
Modeling Socio-economic, Agent Based Models

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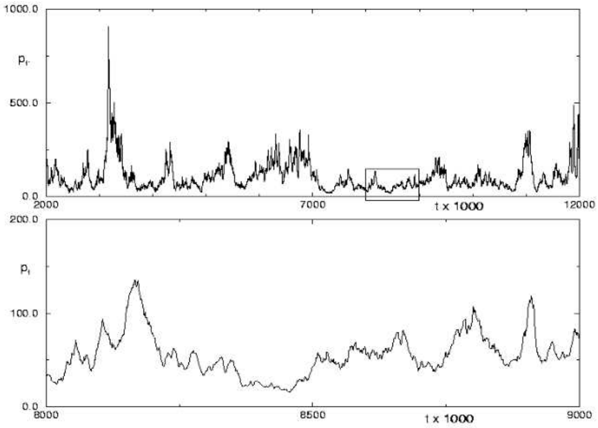
• Economics and Finance

Probably the most complex system is human behaviour!

Even by considering only the trading between individuals, situation seem to be incredibly complicated.



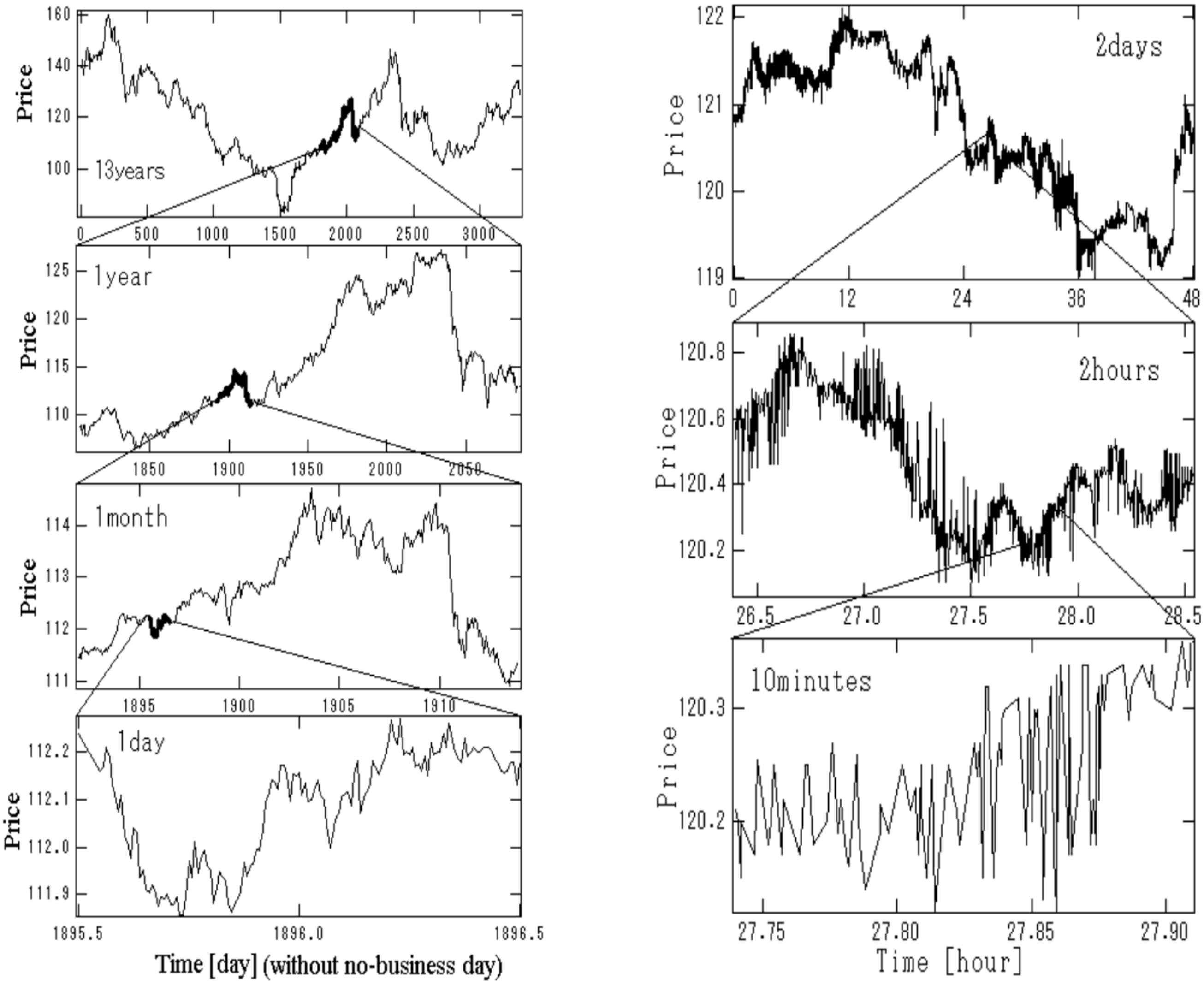
Econophysics tries to understand the basic "active ingredients" at the basis of some peculiar behaviours.

For example price statistical properties can be described through a simple model of agents trading the same stock.

Bachelier and Random Walk (1900)

In 1900 Louis Bachelier, a student of Poincare', in his PhD Thesis: *Theorie de la Speculation,* developed a Random Walk model to explain the dynamics of the stocks exchanged in the Paris Stock Market. His model of Random Walk was theorized 5 years before the famous Einstein's interpretation of the Brownian Motion.

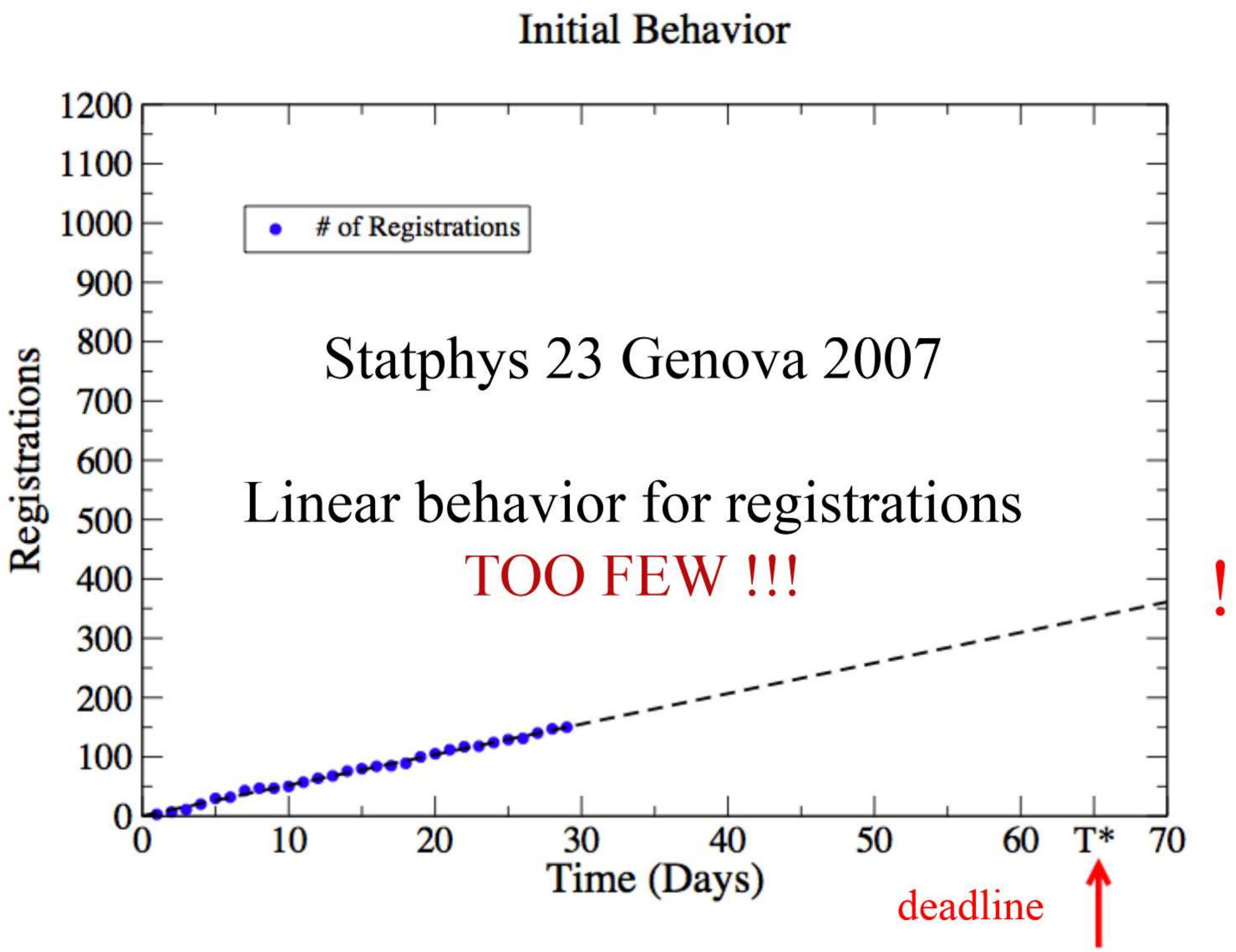
L. Bachelier, Ann. Sci. Ecolole Norm. Super. **17** (1900) 21


13years
1year
1month
1day
Price
Time [day] (without no-business day)
2days
2hours
10minutes
Time [hour]

How people react to a deadline: time distribution of conference registrations

V. Alfi, G. Parisi, L. Pietronero, *Nature Physics*, **746**, 3, (2007)

- Statphys editions: Genoa (Italy) 2007,
- Bangalore (India) 2003, Cancun (Mexico) 2001, Paris (France) 1998.
- For organizers it is very useful to have an idea of the total number of participants to a conference as soon as possible.



Initial Behavior
# of Registrations
Statphys 23 Genova 2007
Linear behavior for registrations
TOO FEW !!!
!
Registrations
Time (Days)
T*
deadline

Linear Behavior

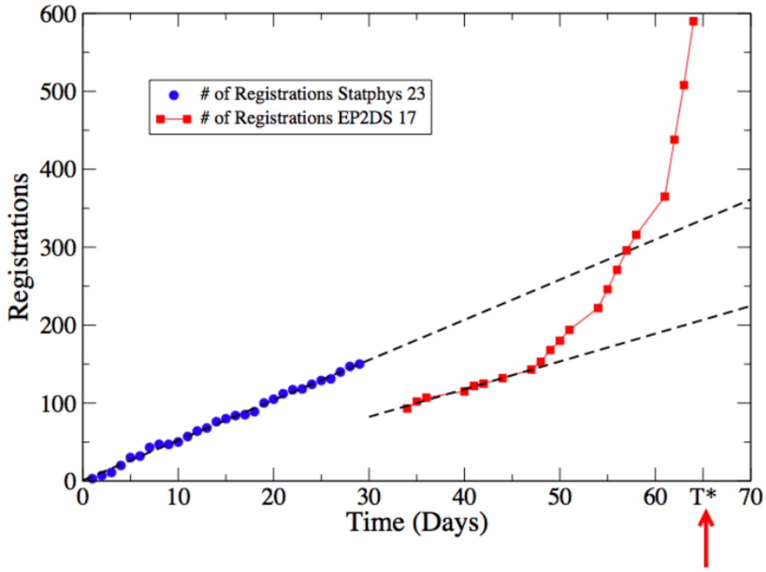
- People tend to postpone their registration because they have other tasks to carry out
- A steepening of the registration curve close to the deadline is therefore expected
- But, how much? Is it possible to predict the total number of participants from the early data?

Comparison with other conferences registrations

• Also the other data set shows an initial linear behavior

• The slope is different because the total number of participant was smaller

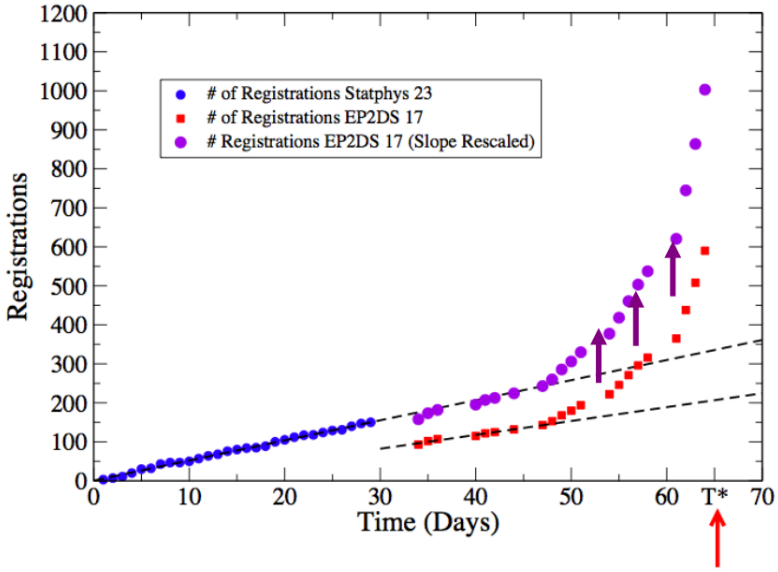
• We are able to have a prediction of the final number of participants by rescaling the data from the other conference to have the same slope of our data



Rescaling the slope

- Rescaling the slope: expectation curve which enable us to predict the final number of participants

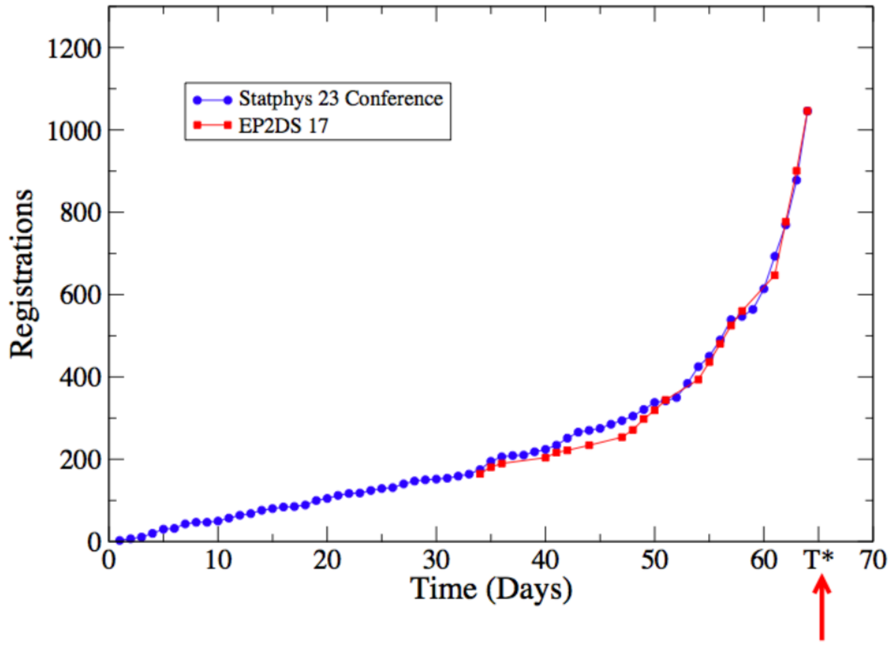
- According to the prediction the final number of registration should exceed the value of 1000, a number 3 times larger than the one expected from the linear extrapolation



A posteriori comparison

• The prediction reproduces the actual behavior accurately

• The similarity of the two curves suggests an <u>universal behavior</u> and probably a simple model



Simplest Model

Pressure to register at time t increase inversely proportional to the distance from the deadline T*:

$$P(t) = \frac{C}{T^* - t}$$

T^* = deadline

C = constant fixed by the total number of registrations

Number of registrations

$$N(t) = C \int_0^t p(s)[M - N(s)]ds$$

M = entire population of possible participants

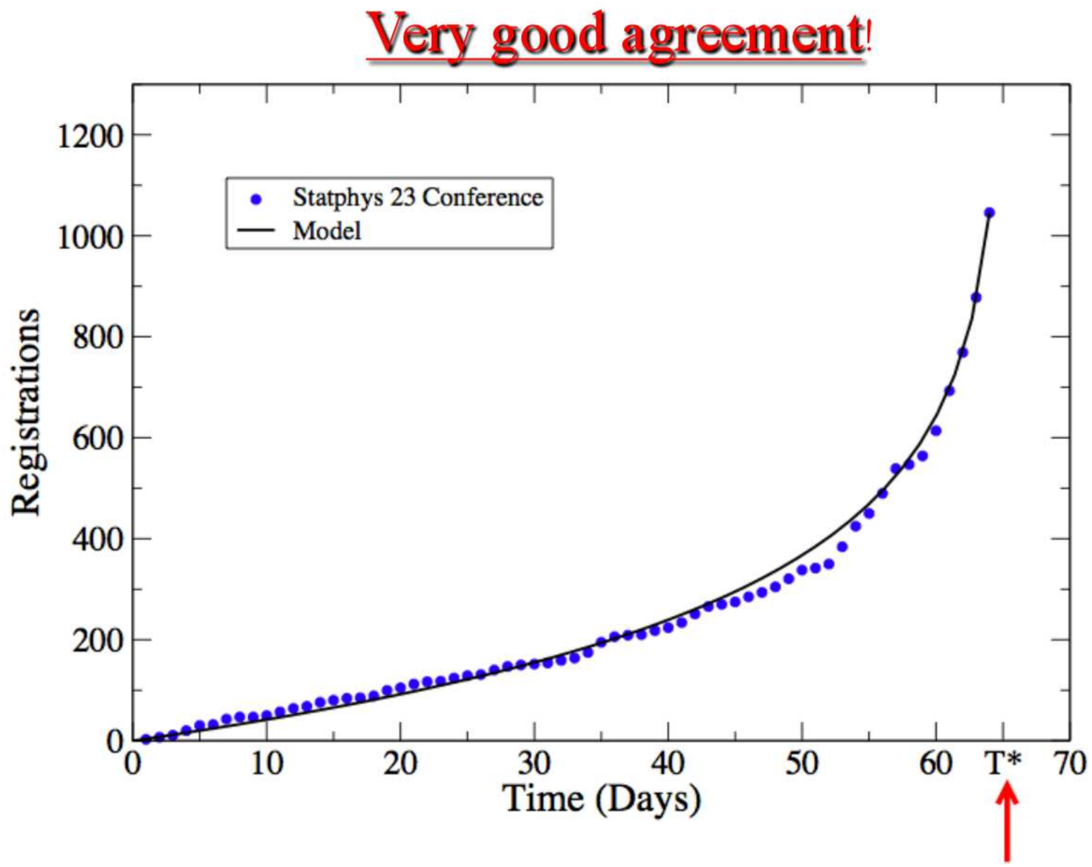
Approximation

$$M >> N_{tot}$$

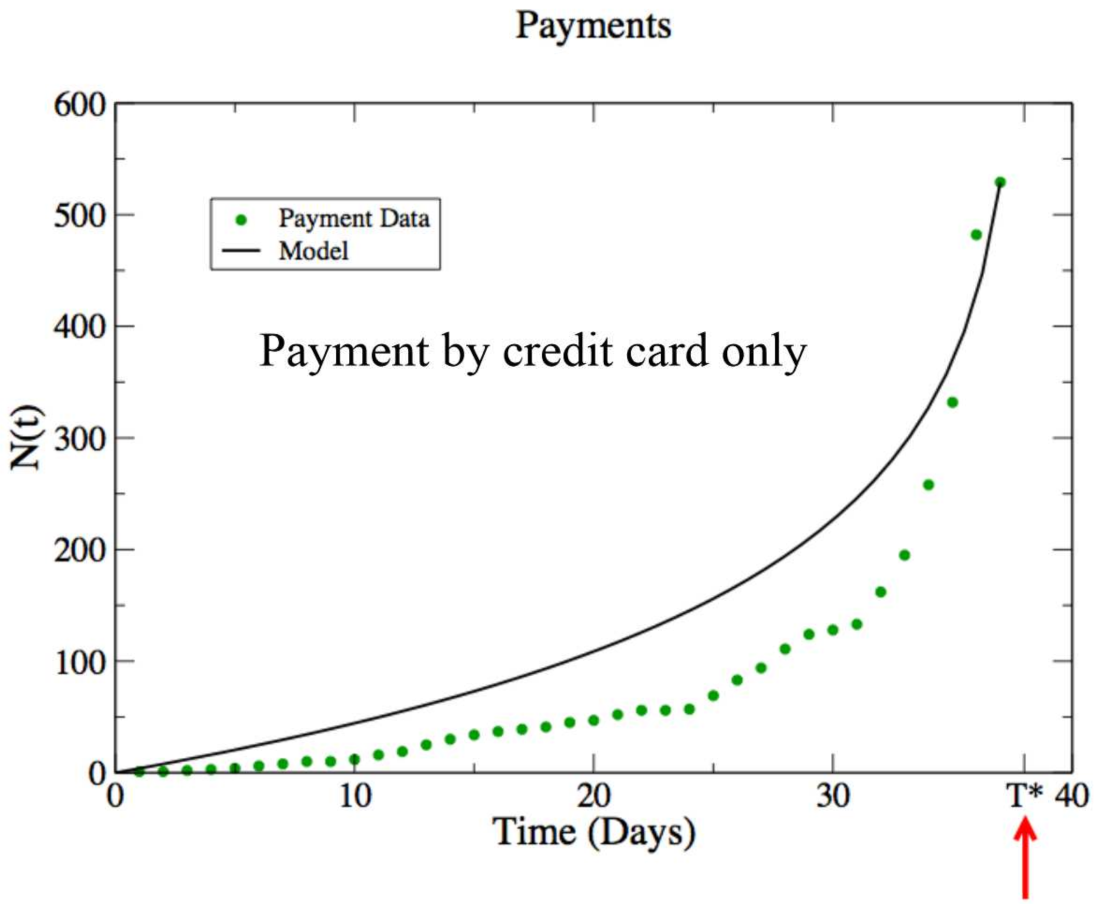
$$N(t) = C \int_0^t p(s) ds = C \ln(\frac{T^*}{T^* - t})$$

NB: **log-singularity is regularized with Δt=1day**

Comparison Model-Data



Model vs Payment Data



- The model assumes that probability to register is uniform in the remaining time

- There is no real tendency to postpone the registration towards the deadline

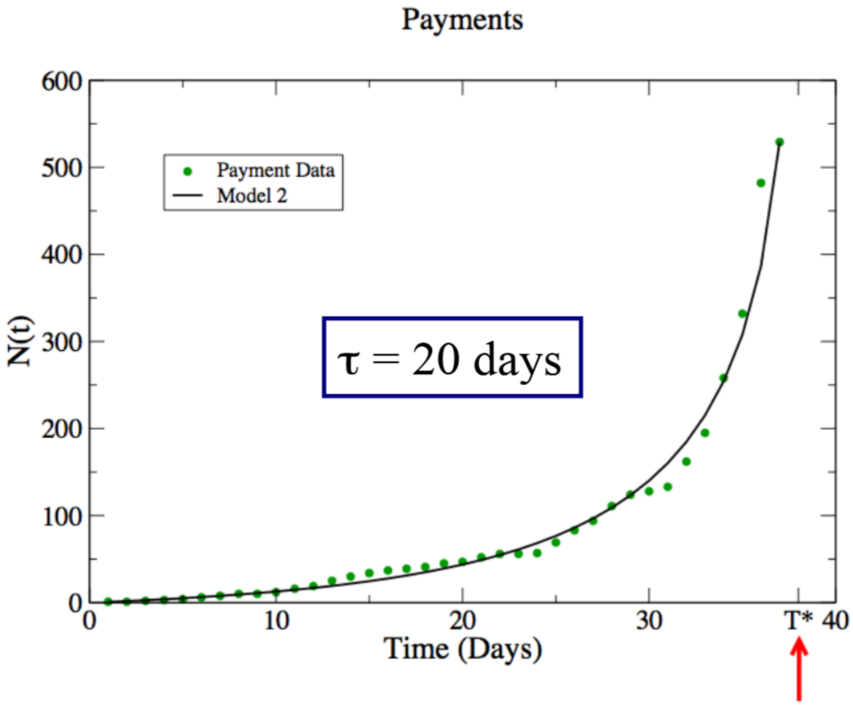
- This is rather unrealistic in the case of payment: optimal would be to pay the last day but this may conflict with other tasks

Payment Model

$$N(t) = C \int_0^t p(s) \exp(-\frac{T^* - s}{\tau}) ds$$

Data vs Model 2

- Including the exponential term the model fits the payment data rather well
- The estimation of the characteristic time to postpone is τ ~ 20 days



The Economist

NOVEMBER 1ST - 7TH 1997

CAMBODIA'S MISERY
page 27

SUHARTO AND THE IMF
page 31

A week on the wild side

Top ten postwar movements in S&P index and their "causes"

	Date	Percent Change	New York Times Explanation
1	Oct. 19, 1987	-20.47%	Worry over dollar decline and trade deficit; Fear of US not supporting dollar.
2	Oct. 21, 1987	9.10%	Interest rates continue to fall; deficit talks in Washington; bargain hunting.
3	Oct. 26, 1987	-8.28%	Fear of budget deficits; margin calls; reaction to falling foreign stocks
4	Sep. 3, 1946	-6.73%	"...no basic reason for the assault on prices."
5	May 28, 1962	-6.68%	Kennedy forces rollback of steel price hike.
6	Sep. 26, 1955	-6.62%	Eisenhower suffers heart attack.
7	Jun. 26, 1950	-5.38%	Outbreak of Korean War.
8	Oct. 20, 1987	5.33%	Investors looking for "quality stocks".
9	Sep. 9, 1946	-5.24%	Labor unrest in maritime and trucking industries.
10	Oct. 16, 1987	-5.16%	Fear of trade deficit; fear of higher interest rates; tension with Iran.

Lessons from the crisis for macroeconomics and finance theory

Jean-Claude Trichet, President of ECB, Frankfurt, 18 November 2010

- Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner.

- As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools.

- We need to deal better with heterogeneity across agents and the interaction among those heterogeneous agents. We need to entertain alternative motivations for economic choices. Behavioural economics draws on psychology to explain decisions made in crisis circumstances. Agent-based modelling dispenses with the optimisation assumption and allows for more complex interactions between agents. Such approaches are worthy of our attention.

- In this context, I would very much welcome inspiration from other disciplines: physics, engineering, psychology, biology. Bringing experts from these fields together with economists and central bankers is potentially very creative and valuable.

- Scientists have developed sophisticated tools for analysing complex dynamic systems in a rigorous way. These models have proved helpful in understanding many important but complex phenomena: epidemics, weather patterns, crowd psychology, magnetic fields. Such tools have been applied by market practitioners to portfolio management decisions, on occasion with some success.

- I am hopeful that central banks can also benefit from these insights in developing tools to analyse financial markets and monetary policy transmission.

Classical Economics Approach

Assumptions of classical economics

- Efficient Market
- General Equilibrium
- Rational Full-Informed Agents
- Price changes correspond to new information

and Rational Agents behave in the following way

- Agents make only rational choices
- Agents are full aware of the environment
- Agents are benefit (utility) maximizers

Why these hypothesis?

These assumptions are needed to find closed and analytical solutions of models ...

Official reports on the 2008 Crisis:

- Mid 2008: Danish Central Bank

  Worst scenario: subprime continues, US recession, increase of 2.5% of interbank interest. Basic stability of the bank system !!!

- Feb. 25, 2009: de Larosiere EEC Report

  Financial crisis - real economy - No more Trust

  Risk mispriced, excessive leverage

  Regulations on individuals but not on macro systemic risk - Contagion - Correlations

- NB: SAME STARTING INFORMATION BUT COMPLETELY DIFFERENT CONCLUSIONS

  (A FEW MONTHS LATER)

<u>PROBLEMS WITH CAUSE-EFFECT RELATION</u>

Problems with the classic theory:

- ***Great cathastrofic events like the '87 crash, the Inernet bubble of 2000 and the recent case of the Subprimes do not seem to have any relation with specific events or new information***

- ***Also the Stylized Facts at smaller scales cannot be really explained within the standard model***

- ***Breaking of the cause-effect relation: then what is the real origin of large price changes?***

Complex Systems:

- ***Emergence of collective properties in systems with many interactive components***
  i.e. quarks, atoms, proteins, bacteria
  but also people and institutions

- ***Reductionism:*** ***elementary constituents (bricks)***
- ***Complexity:*** ***emergent structures (architecture)***

- ***Complex vs complicate***

- ***Importance of large amount of data; computer***

Systemic Risk Problem

- After the subprime crisis there have been many conjectures for the possibile origin of this instability. Most suggestions focus on concepts like collective behavior, contagion, network domino effect, coherent portfolios, lack of trust, liquidity crisis, leverage effect and, in general psycological components in the traders behavior.

- Standard risk analysis is usually linear analysis within a cause-effect relation. Possibly new insight to the risk problem could profit could be inspired by complex systems theory.

- Different perspective in which the interaction between agents (direct or in direct) is explicitely considered together with the idea that the system may become globally unstable in the sense of self-organized criticality. The analysis is therefore shifted from the linear cause-effect relation to the study of the possibile (nonlinear) intrinsic instabilities.

- To achieve this goal it is essential to increase the number and quality of the Stylized Facts are identified from the massive data available. This should lead to a quality analysis for Agent Based Models. From Methaphoras to Real Scientific Tools.

OUR PERSPECTIVE

- *Workable* ABM, clear math and properties
- New elements: N variable, Stylized Facts due to Finite Size Effects, Self-organization
- Approximate scaling, no strict universality: effective exponents depend on situation
- Liquidity crises: Order Book Model for finite liquidity
- ABM in the Global Network, Leverage
- Coherence, correlated portfolios, similar behavior; risky

Key Concepts:

TO IDENTIFY FROM REAL DATA

- Market sentiment, stabilizing vs destabilizing
- The effective independent agents N* in a market
- Analysis of Herding, Contagion, Correlations
- Liquidity analysis of order book
- Network oriented approach - Direct interaction vs global Trust.
- Coherence problem, similar behavior

BASIC STRATEGIC PROBLEM

- Efficiency vs. Robustness

Forecasting Financial Crisis: Measurements, Models and Predictions (ISC-FET Open Call 2010-2014)

- ISC-CNR, Italy (G. Caldarelli, S. Leonardi and LP)
- Univ. delle Marche, Italy (M. Gallegati, D. Delli Gatti)
- ETH Zurich (F. Schweitzer, S. Battiston)
- City Univ. London, UK (G. Iori, A. Banal-Estanol, S. Jafarely)
- Univ. of Oxford, UK (F. Reed-Tsochas, R. May, E. Lopez)
- Yahoo Research, Barcelona, Spain (R. Baeza-Yatez)
- European Central Bank, Frankfurt, D

<u>Complex Systems:</u>

- ***Emergence of collective properties in systems with many interactive components i.e. quarks, atoms, proteins, bacteria but also people and institutions***

- ***<u>Reductionism:</u> elementary constituents (bricks)***
- ***<u>Complexity:</u> emergent structures (architecture)***

- ***Complex vs complicate***

- ***Importance of large amount of data; computer***

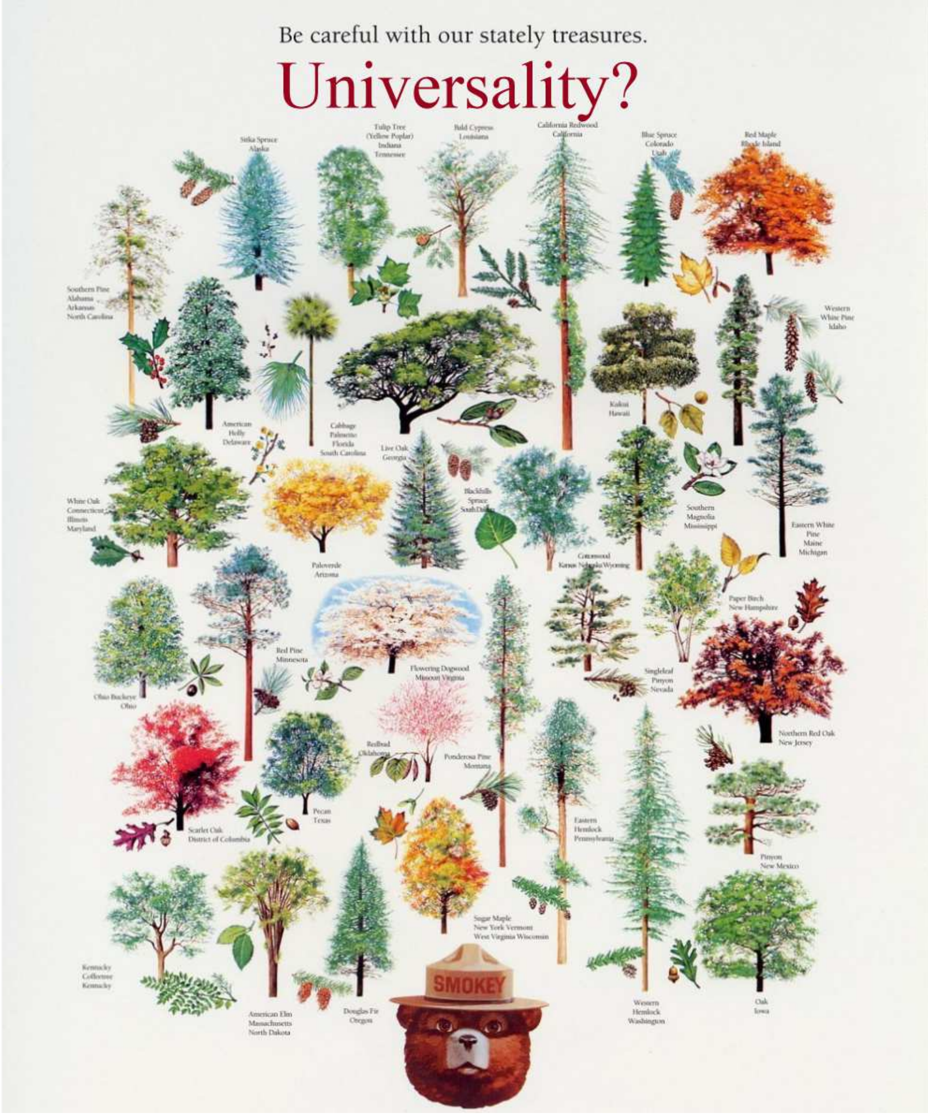
MODELS AND BASIC PROBLEMS

*Ising * (1911)*
Scaling, Criticality (64 - 70)
and RG Group (>72)
Percolation ('70-'80)*
Glasses Spin Glasses* etc.(>74)
Deterministic Chaos* (78)
Fractal Geometry ('80-'90)
Polymers and Soft Matter
***Dynamical Systems** and Turbulence*
Fractal Growth Physical Models:
DLA/DBM (82-84)*
Selforganized Criticality
Sandpile* (87)
Granular Systems ('90)
Minority Game ('97)
Rare Events
Complex Networks (>2000)

INTERDISCIPLINARY APPLICATIONS

Condensed Matter problems
Phase Transitions
Magnetic Systems
Bio-inspired Problems
Astrophysics
Geophysics
Information Theory
Optimization
Economics and Finance
Social Sciences (Random Walk, Bachelier 1900)
Agent Based Models (very many)
Apply old Models or develop New Models?
Universality?

In nature trees are
alike but not identical.
Similarity and common
basic structure but
no strict universality.
Exponents can therefore
depend on specific
situations:
richness to be explored.



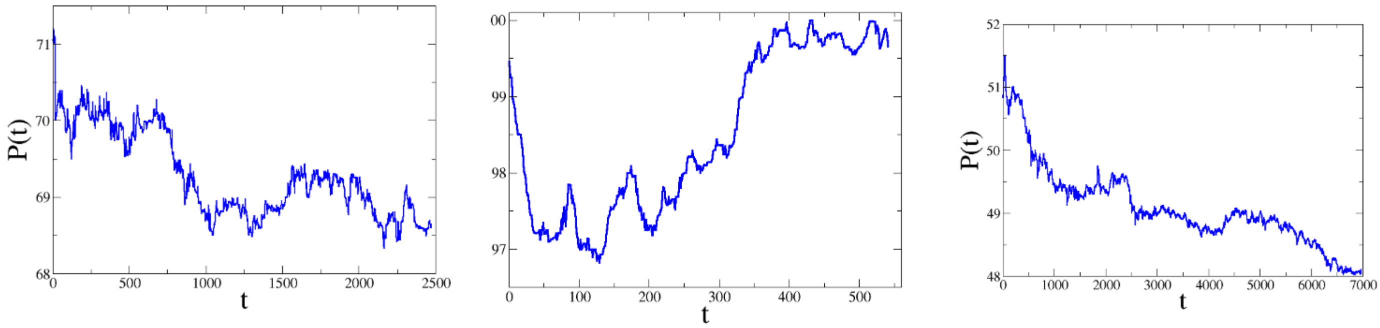
Stylized Facts (Very few; Universal?):

- *Arbitrage -- Random Walk (B&S)*
- *Fat tails, Volatility Clustering etc.*

AND ALSO

- *Non stationarity*
- *Self-organization, Liquidity*
- *Global Network*

NYSE stock-price data



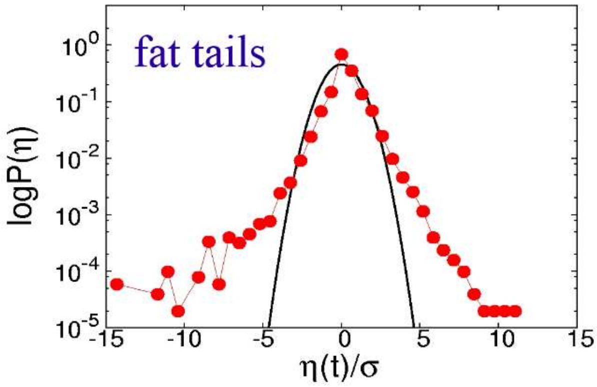
Arbitrage condition: no correlations between price returns

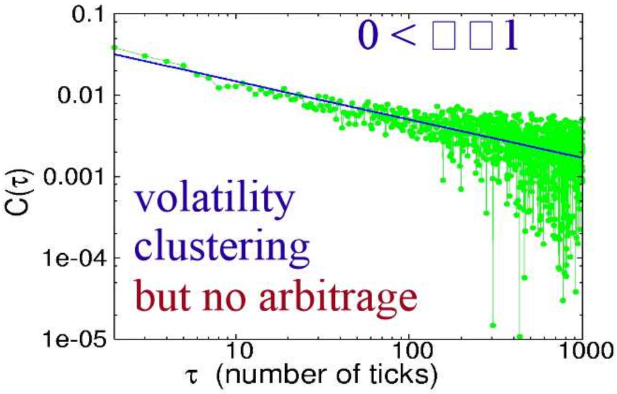
Simplest model: Random Walk

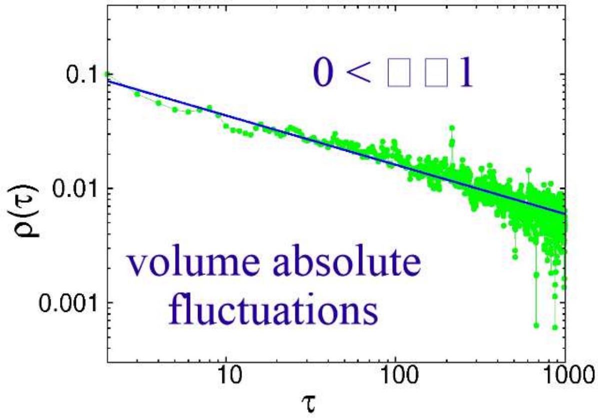
Persistent deviations from RW: Stylized Facts

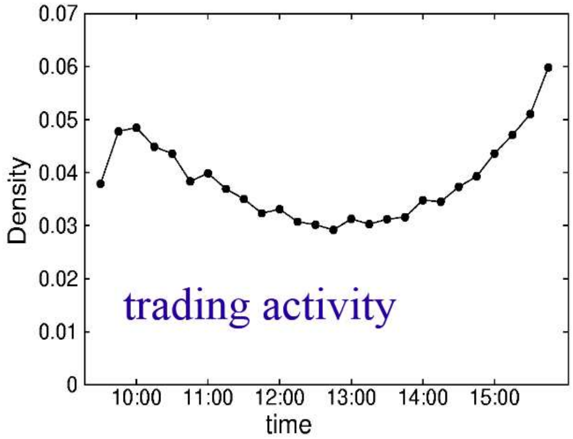
Origin of Stylized Facts: Agent Based Models

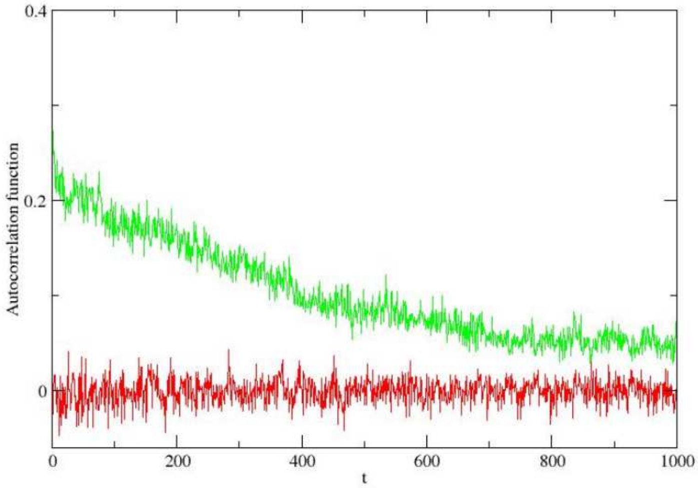
Stylized Facts of Financial Data



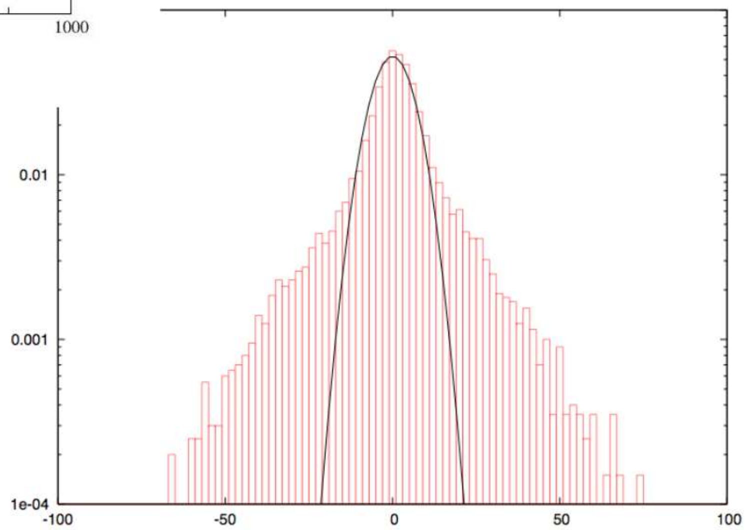








Autocorrelation functions of returns and square returns

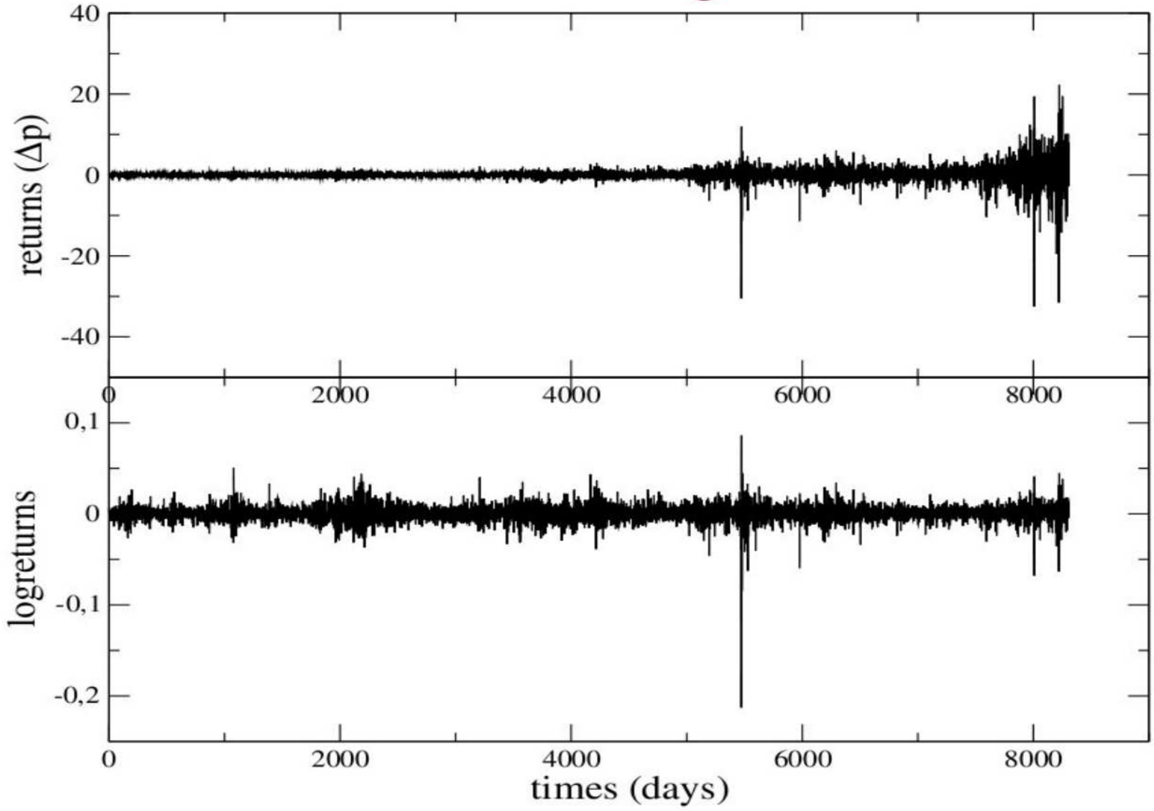


Probability density function of price-returns

Nonstationarity

- Another interesting property of the complex
- random walk for real price is that the drift and the diffusion rate are not constant in time

Return vs logreturns



$$r(t) = \frac{p(t) - p(t-1)}{p(t-1)} = \frac{\delta p}{p} \approx \log p(t) - \log p(t-1)$$

How does an ABM work?

Bottom-up approach: a large number of units (agents) interacts at the microscopic level in a non linear way. The macroscopic dynamics emerges from the cooperation/interactions at the microscopic level.
A typical ABM is a Complex System because the properties of the macroscopic level cannot be only described in terms of the properties of the microscopic units

Applications

Traffic simulations, Human behavior, Epidemics, Ecology, Economics

Scientific Problem

Phenomenological approach

- Black, Scholes e Merton formula
- Differential Stochastic Equation
- ARCH, GARCH, ...
- and many others

Microscopic approach

- Classical Economics
- ABM
- *?!?! Economics Field Theory ?!?!*

Why do we need Agent-Based Models?

Because we are searching to build a microscopic theory for markets and the ABMs are indeed the answer to this task (given by physicists)

CLASSICAL ECONOMICS

Fully Rational Homogeneous Agents: one can describe the dynamics by using a sort of representative agent: *homo economicus*.
The dynamics can be described by a set of differential equations.

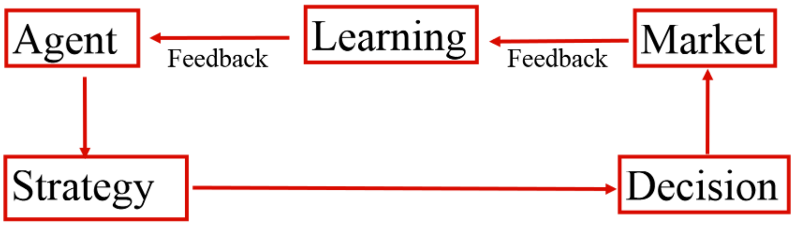
ABM PERSPECTIVE

Bounded Rational Heterogeneous Agents: it is no more possible to describe the dynamics by means of differential equations. Another approach is needed.
Realistic Approach: ABM

ABM ... in practice

Microscopic approach: ABMs analyze how the macroscopic observable (price) are possibly related to the microscopic structure of the market.

Financial Market is a self-organized system composed by a large number of agents who interact with the only aim of maximizing their own capital without exogenous information.



Recovering stylized facts of financial markets from the ABM.

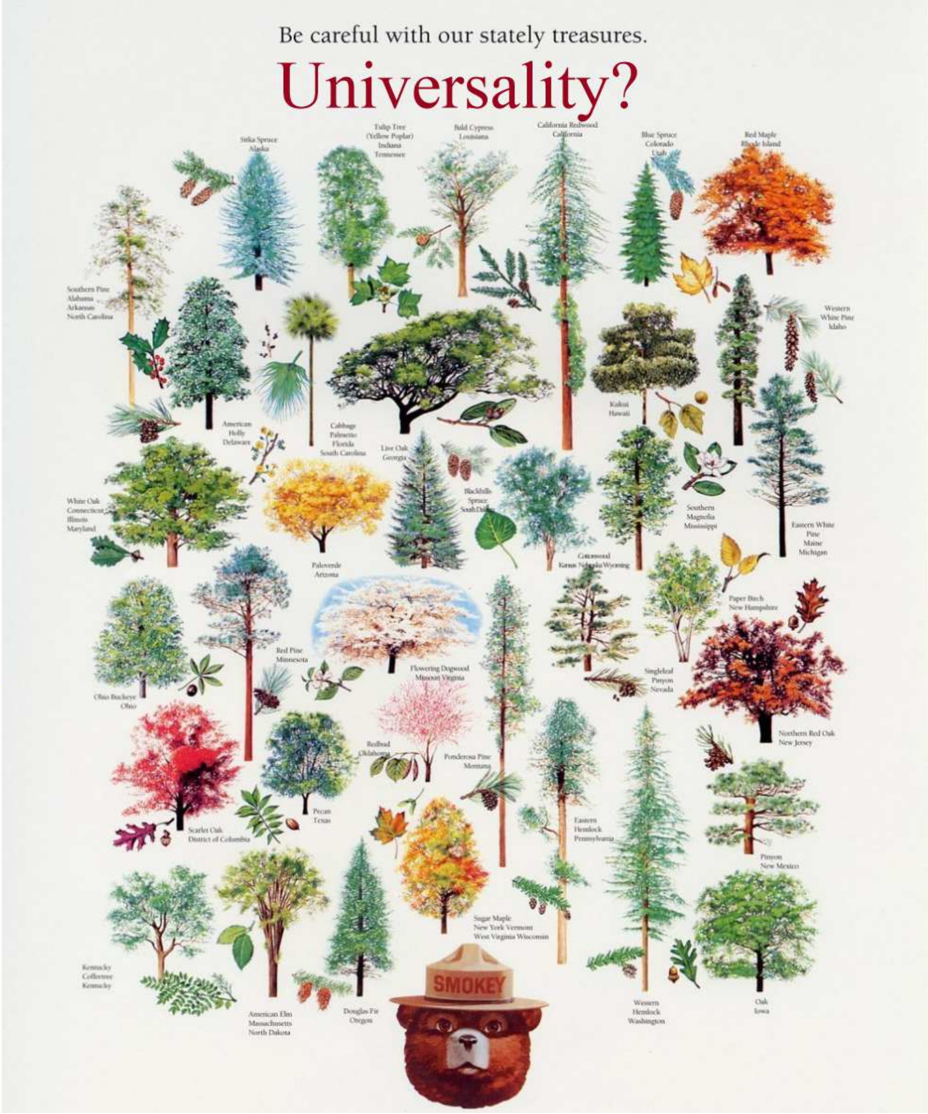
Agent-based modeling as an analytical bridge between the statistical properties of financial data and micro-simulation properties that cause them.

An *incomplete* list of ABMs

- The first ABM: Kim e Markowitz (1989)
- The model of Levy, Levy e Solomon (1994)
- Caldarelli, Marsili, Zhang's model for Stock Exchange markets (1996)
- Percolation theory applied in Finance: Cont & Bouchaud (2000)
- The model of Santa Fe Institute: W.B. Arthur et al. (1996-1999)
- *Minority games: Challet, Zhang et al. (1996)*
- Model for opinion dynamics: Kirman (1993)
- Lux and Marchesi's model and simplified versions (1999 - present)
- Bouchaud, Giardina's model for volatility clustering (2004)
- Gallegati, Stiglitz et al.: a model for credit network and bank defaults
- mini ABMs to study / test a specific aspect: Farmer, Bouchaud, ...

Universality?

In nature trees are
alike but not identical.
Similarity and common
basic structure but
no strict universality.
Exponents can therefore
depend on specific
situations:
richness to be explored.



Lux and Marchesi's Model (1999-2000)

Competition between chartist and fundamentalist traders

Chartists: follow the market trend, evaluate historical series (DESTABILIZING EFFECT)

Fundamentalists: believe that a fundamental price exists and try to drive the price toward this price (STABILIZING EFFECT)

+

Opinion dynamics: herding

Endogenous mechanism for price formation

Drawbacks: too many parameters and too aesthetic features added to the four main ingredients

Classes of agents

- Fundamentalist agents assign a reference value p_f to a stock depending on economic analysis)

- Chartists, divided in:
  - Optimists
  - Pessimists

Conservation laws for the agents

$$n_c + n_f = N \qquad\qquad n_+ + n_- = n_c$$

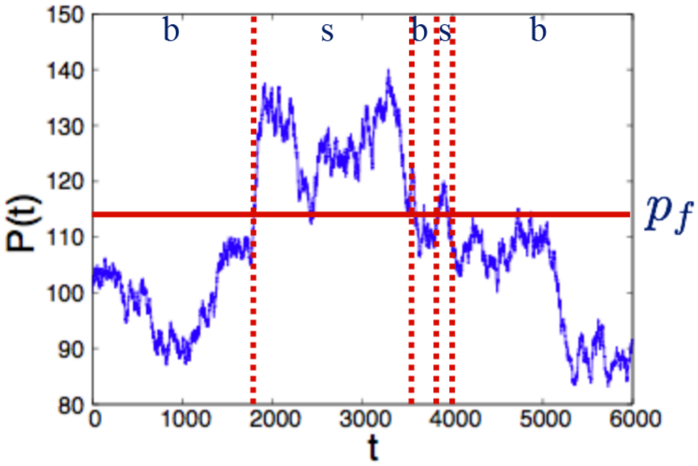
Fundamentalist agents

Traditional investors: the only class of investors according to the Standard Model of Economics

They assume the existence of a fundamental price that represents the fair value of the stock. In such a framework the unique strategy is

buy if $p(t) < p_f$

sell if $p(t) > p_f$

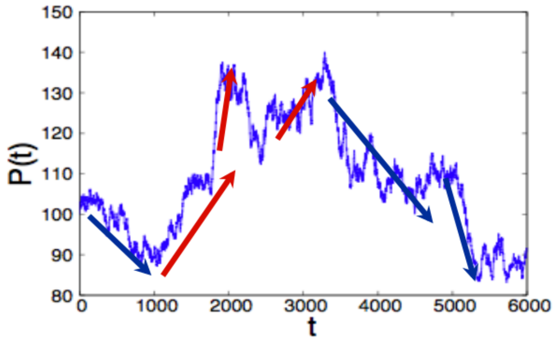


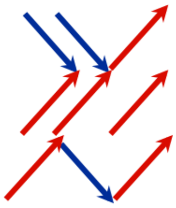
Chartist agents: noise traders

According to the Standard Model of Economics these agents should not exist

- Optimists: buy (in any case)
- Pessimists: sell (in any case)

They analyze the market trend in "quasi" mathematical terms having as a basis the time series {p(t)}





trends produce the investor actions in the market

Opinion dynamics: pessimistics vs optimistics - transition probabilities

Probability per unit of time that pessimist becomes optimist and viceversa

$$\pi_{+-} = v_1 \frac{n_c}{N} \exp U_1$$

$$\pi_{-+} = v_1 \frac{n_c}{N} \exp(-U_1)$$

$$U_1 = \alpha_1 x + \frac{\alpha_2}{v_1} \frac{dp}{dt} \frac{1}{p}$$

Basic criteria: price trend + herding

Opinion dynamics: chartists vs fundamentalists - transition probabilities

Probability per unit of time

$$\pi_{+f} = v_2 \frac{n_+}{N} \exp(U_{2,1})$$

$$\pi_{-f} = v_2 \frac{n_-}{N} \exp(U_{2,2})$$

$$\pi_{f+} = v_2 \frac{n_f}{N} \exp(-U_{2,1})$$

$$\pi_{f-} = v_2 \frac{n_f}{N} \exp(-U_{2,2})$$

$$U_{2,1} = \alpha_3 \left\{ \frac{r + \frac{1}{v_2}\frac{dp}{dt}}{r} - R - s\left| \frac{p_f - p}{p} \right| \right\} \qquad U_{2,2} = \alpha_3 \left\{ R - \frac{r + \frac{1}{v_2}\frac{dp}{dt}}{r} - s\left| \frac{p_f - p}{p} \right| \right\}$$

Basic criteria: price trend + herding

Price formation

Each Δt price changes by

$$\Delta p = \pm 0.001 p$$

with probability

$$\pi_{\uparrow p} = \max[0, \beta(ED + \mu)]$$

$$\pi_{\downarrow p} = -\min[\beta(ED + \mu), 0]$$

This set of equation for price formation is equivalent to the Walrasian mechanism of price adjustment

$$\frac{1}{p}\frac{\mathrm{d}p}{\mathrm{d}t} = \beta\, ED$$

$$N_c + N_f = N = \text{cost}$$
$$n_+ + n_- = N_c$$

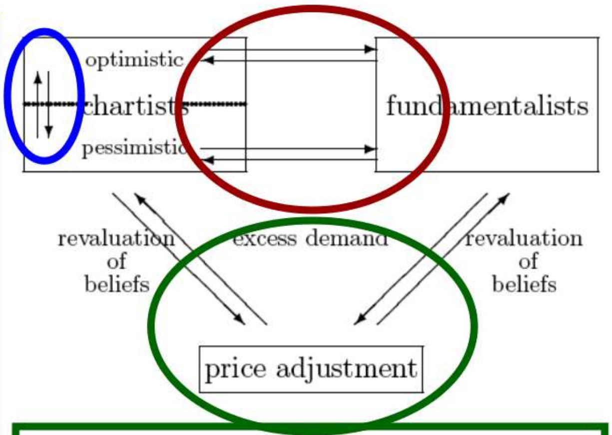
The "terrible" dynamics of L&M

$$x = \frac{n_+ - n_-}{N_c}$$

$$\pi_{+-} = v_1 \frac{n_c}{N} \exp U_1$$

$$\pi_{-+} = v_1 \frac{n_c}{N} \exp(-U_1)$$

$$U_1 = \alpha_1 x + \frac{\alpha_2}{v_1} \frac{dp}{dt} \frac{1}{p}$$



$$\pi_{+f} = v_2 \frac{n_+}{N} \exp(U_{2,1})$$

$$\pi_{-f} = v_2 \frac{n_-}{N} \exp(U_{2,2})$$

$$\pi_{f+} = v_2 \frac{n_f}{N} \exp(-U_{2,1})$$

$$\pi_{f-} = v_2 \frac{n_f}{N} \exp(-U_{2,2})$$

$$U_{2,1} = \alpha_3 \left\{ \frac{r + \frac{1}{v_2}\frac{dp}{dt}}{r} - R - s \left| \frac{p_f - p}{p} \right| \right\}$$

$$U_{2,2} = \alpha_3 \left\{ R - \frac{r + \frac{1}{v_2}\frac{dp}{dt}}{r} - s \left| \frac{p_f - p}{p} \right| \right\}$$

$$ED_c = (n_+ - n_-)t_c \quad ; \quad ED_f = n_f \gamma \frac{p_f - p}{p}$$

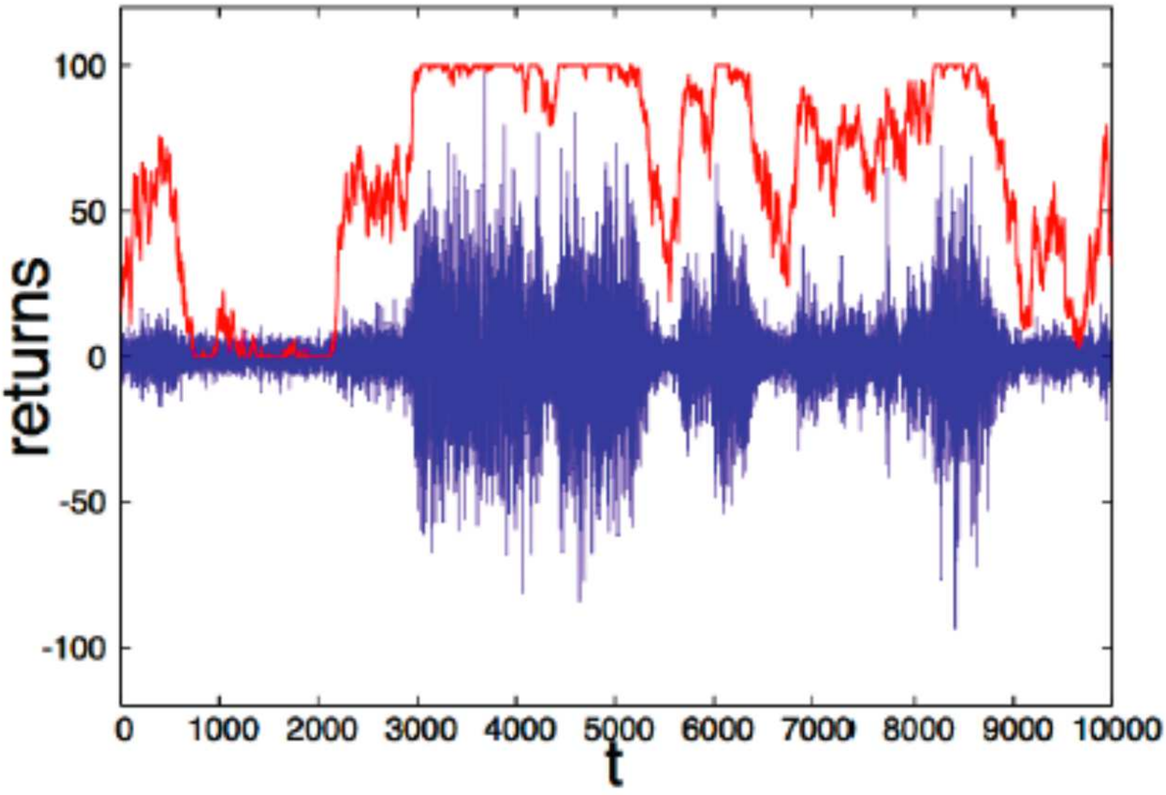
$$ED = ED_c + ED_f$$

$$\Delta t \rightarrow \Delta p = \pm 0.001 p$$

$$\pi_{\uparrow\downarrow p} = \pm \max[0, \beta(ED + \mu)] \quad \Leftrightarrow \quad \frac{1}{p}\frac{dp}{dt} = \beta \cdot ED$$

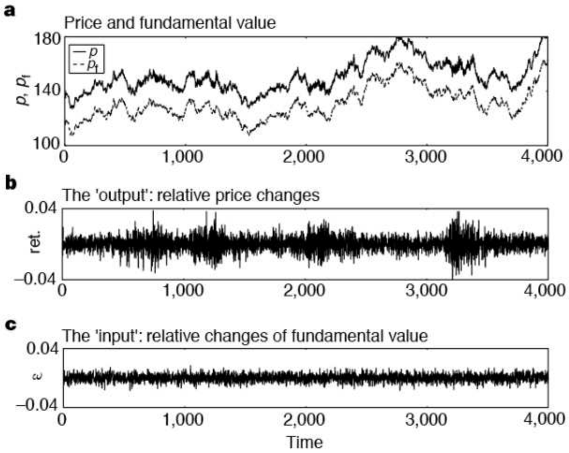
$$\ln(p_{f,t}) - \ln(p_{f,t-1}) = \epsilon_t \quad \epsilon_t \sim N(0, \sigma_\epsilon)$$

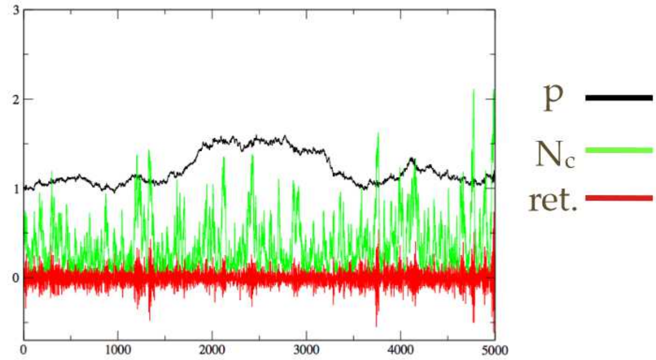
What gives what ???

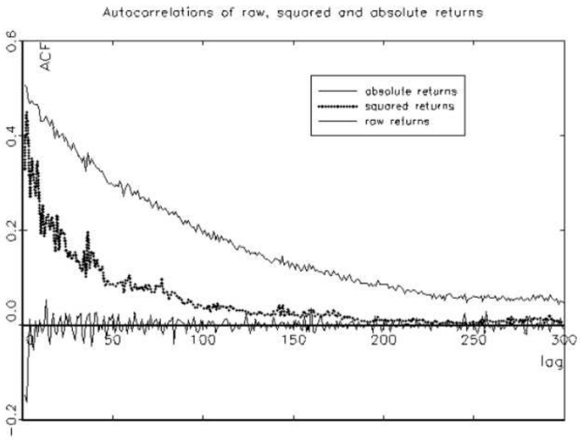


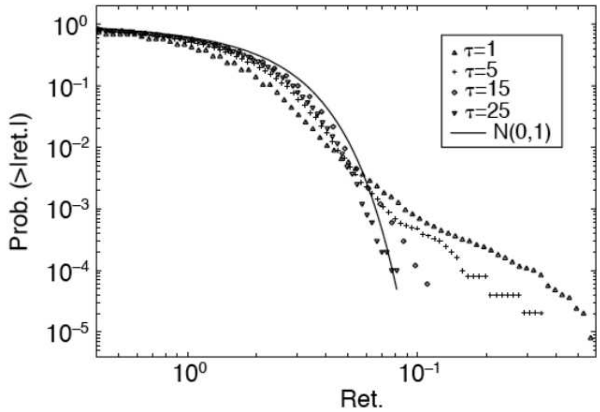
Volatility clustering is due to the opinion intermittecy

$$N = 500, v_1 = 3, v_2 = 2, \beta = 6, T_c(= Nt_c) = 10, T_f(N\gamma) = 5, \alpha_1 = 0.6$$
$$\alpha_2 = 0.2, \alpha_3 = 0.5, p_f = 10, r = 0.004, R(= r/p_f) = 0.0004, s = 0.75$$









Market dynamics is the result of a competition between different kind of agents, each with its own strategy. Market stylized facts can be well reproduced.

Problems:

- 13 parameters: the role of each is not clear
- Finite size effects seem to be critical and not controlled
  Realistic results are obtained only for N=500???
- Origin of Stylized Facts remains unclear

One should artificially avoid that the number of chartists/ fundamentalists goes to zero (absorbing states).

This is achieved by introducing a minimal "ad hoc" value for the number of chartists and fundamentalists.
In L&M this value is set to be 4 (a priori)

In the end how many parameters?

3 α, 2 ν, β, γ, tc , pf, r, R, s, σ = 13 parameters

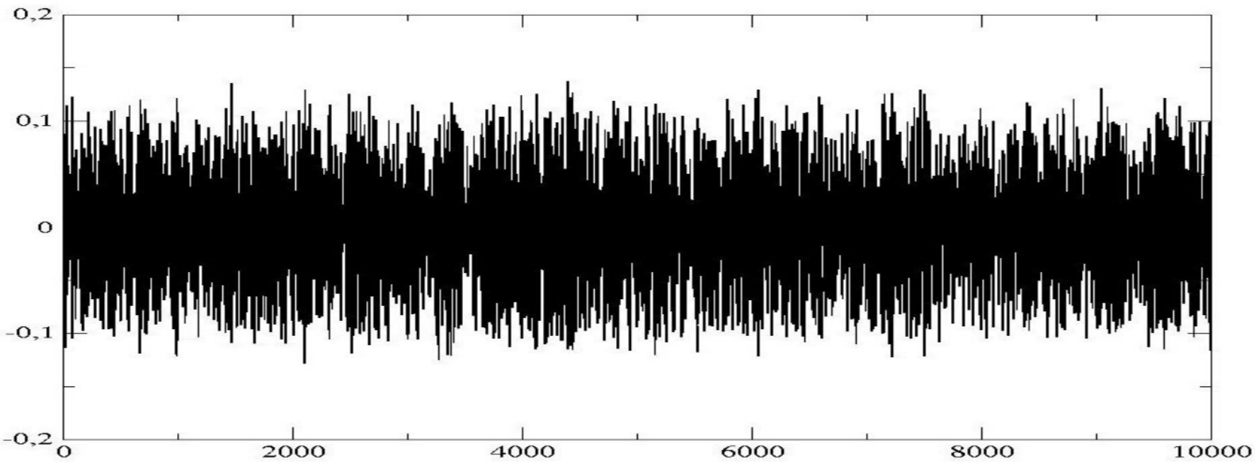
13 parameters with a strongly nonlinear dynamics!

But what does this mean in terms of
- Stability
- Self-organization, etc

Stability with respect to variations of the parameters

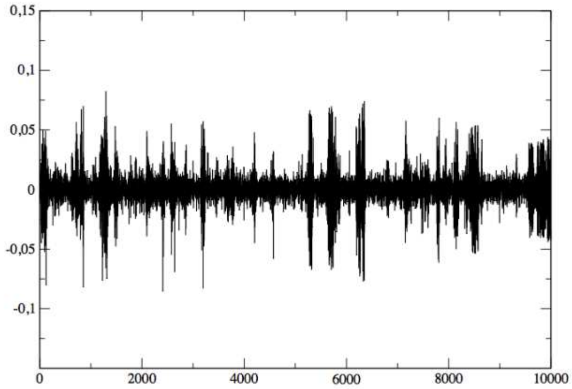
Puzzle of the N-dependence (Egenter, Lux, Stauffer, '99)

- For N=5000 one looses volatility clustering:



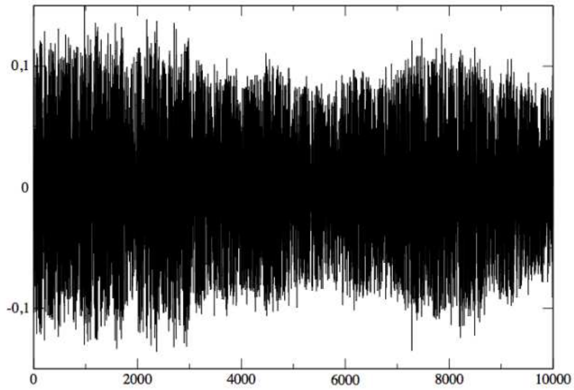
Price Returns

Intermittent behavior: OK

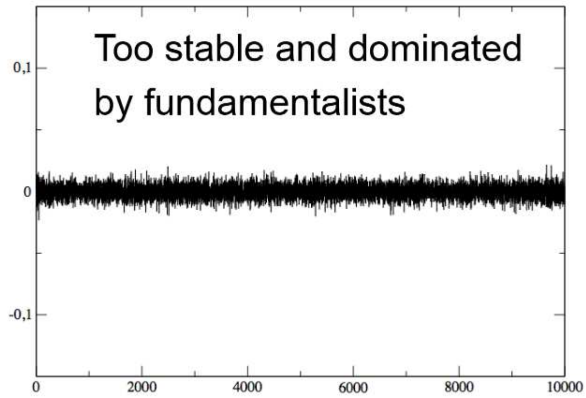


N=500

Changes of opinion are too fast



N =50



N 5000

Stability with respect to the other parameters

- We have seen that the herding terms (contagious) are essential for the stylized facts
- Therefore we focus on ν, β, γ and tc
- ν from 2-3 to 20-30 or 0.2-0.3: bad
- β from 6 to 0.6 or 60: stable
- γ from 0.01 to 0.1 or 0.001: bad
- tc from 0.02 to 0.2 and 0.002: bad
- Self-organization?

(Parameters are changed one by one)