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# AGENTS IN THE GLOBAL NETWORK: SELF-ORGANIZATION AND INSTABILITIES

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Collaborators:

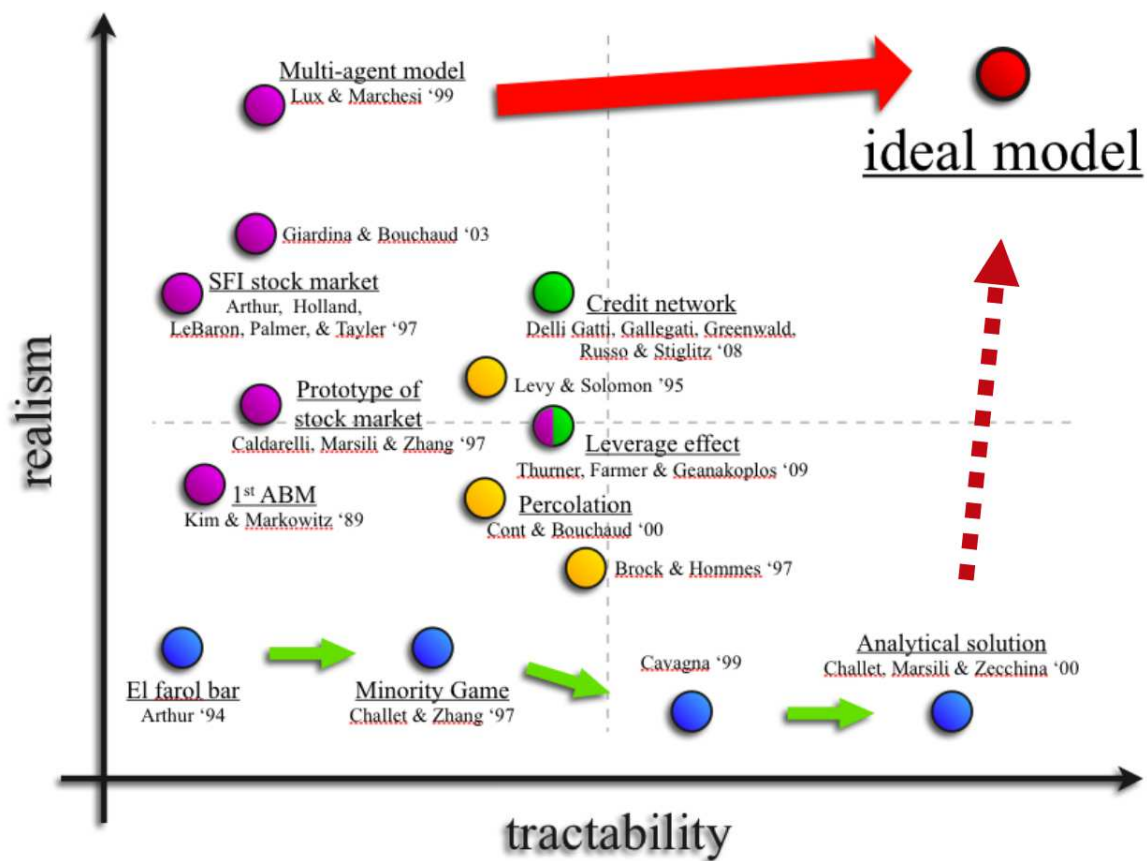
Valentina Alfi, Matthieu Cristelli and Andrea Zaccaria

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(WEB page: <http://pil.phys.uniroma1.it>)

# Summary

- After the subprime crisis there have been many conjectures for the possible 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 **psychological 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 explicitly 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 possible (nonlinear) **intrinsic instabilities**.
- We discuss some steps towards a systematic analysis of these ideas based on agent models and order book models together with the statistical analysis of experimental data. The final objective of these studies would be to **define the characteristic properties** of each of the above concepts from the models and then to **identify their role and importance** in the real financial markets.
- To achieve this goal it is essential to **increase the number and quality of the Stylized Facts** which are identified from the massive data available



Adapted from a picture by M. Marsili

“Critical Review of ABM”, Varenna Lectures 2010  
M. Cristelli, A. Zaccaria and LP

# 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)

+

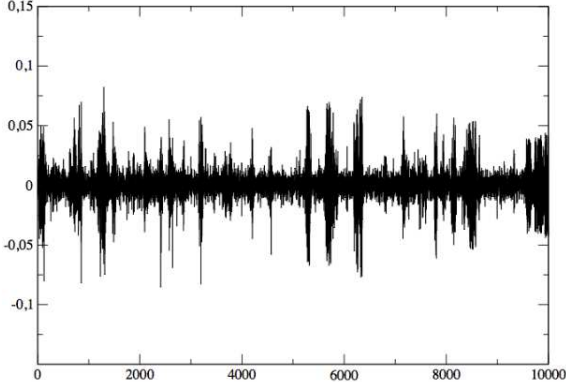
Opinion dynamics: herding

Endogenous mechanism for price formation

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

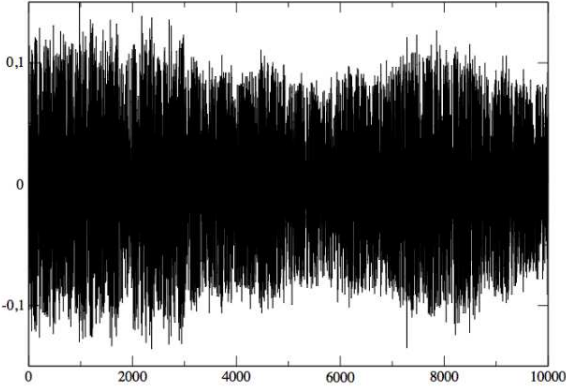
Price  
Returns

Intermittent behavior: OK

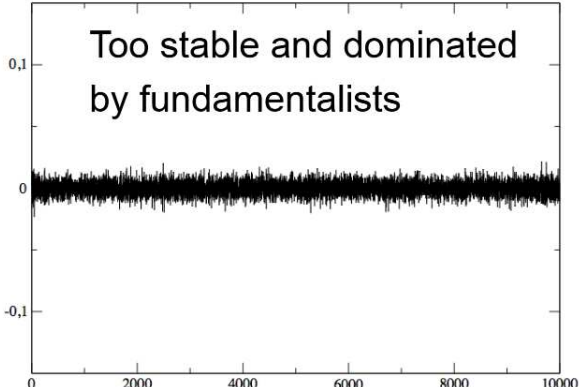


N=500

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  $\beta$ ,  $\alpha$ ,  $\gamma$  and  $\tau_c$
- $\beta$  from 2-3 to 20-30 or 0.2-0.3: bad
- $\alpha$  from 6 to 0.6 or 60: stable
- $\gamma$  from 0.01 to 0.1 or 0.001: bad
- $\tau_c$  from 0.02 to 0.2 and 0.002: bad
- **Self-organization?**

(Parameters are changed one by one)

# 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
- Nature of Bubbles: Critical behavior, Black swan (outliers), Ponzi scheme, ???

# Minimal ABM model

(V. Alfi, M. Cristelli, L.P., A. Zaccaria 2008)

N players:

$N_F$  fundamentalists

$N_C$  chartists

- Chartists characterized by a destabilizing effective potential (much simpler)
- Price formation and excess demand proportional to trader's signals (effective  $N^*$ )
- Specific origin of Stylized Facts (finite size effects)
- Nonstationarity (effective  $N^*$  fluctuations)
- Self-organization to the quasi-critical (intermittent) state



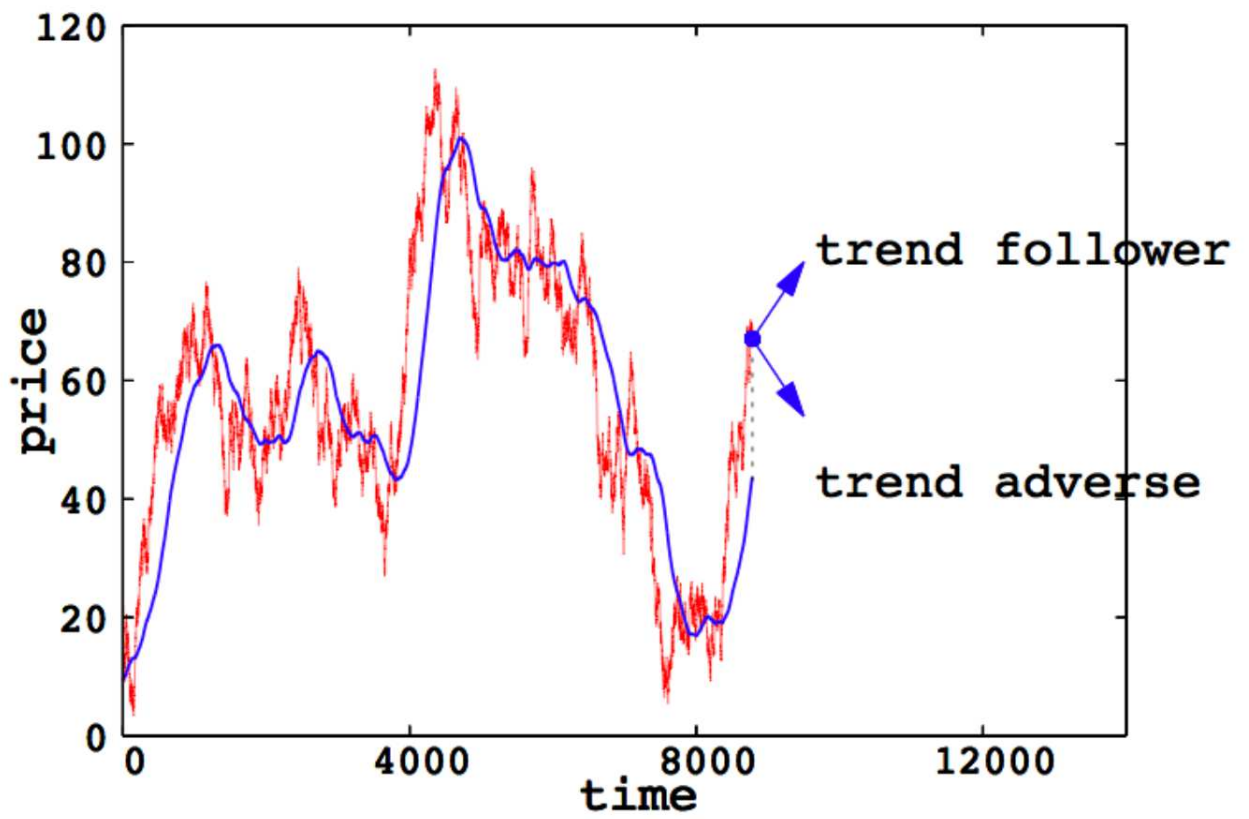
# A new description of Chartists: The Effective Potential Model

- Directional elements are strongly connected with **agents' strategies**.
- This model is based on a random walk with an **active potential** defined on the walk dynamic
- The centre of the potential is the **moving average** of the trajectory of the walker

M.Takayasu, T.Mizuno and H.Takayasu, preprint 2005, [physics/0509020].

V. Alfi, F. Coccetti, M. Marotta, L. Pietronero, M.Takayasu, Physica A, **370**, 30-37, 2006

# Moving Average



The basic ansatz is that price dynamics  $P(t)$  can be described in terms of a stochastic equation of the type:

$$P(t+1) - P(t) = b(t)F[P(t) - P_M(t)] + \sigma(t)\omega(t)$$

↓  
Next  
increment

↓  
The pre-factor  $b(t)$   
gives the sign and  
the strength of the  
potential

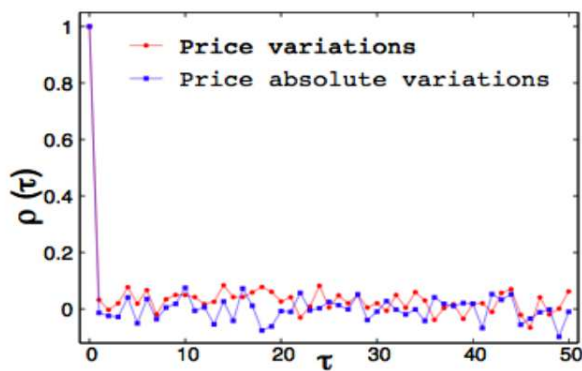
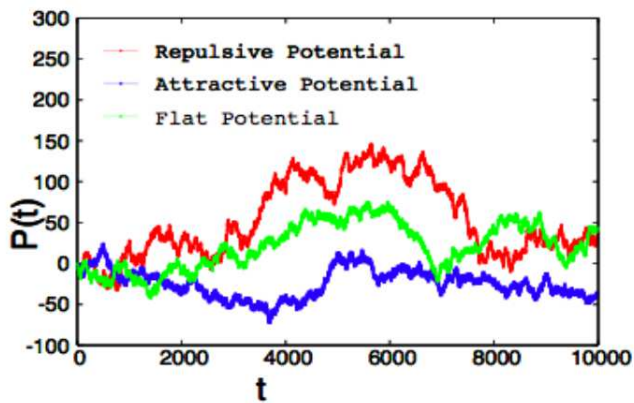
↓  
 $F$  is the  
Force

↓  
Random noise  
with unitary variance  
and zero mean

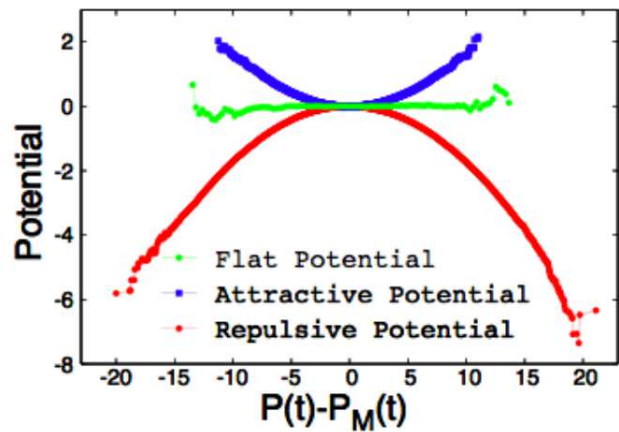
$$P_M(t) = \frac{1}{M} \sum_{k=1}^M P(t-k)$$

The Moving  
Average

The interesting point is that one can identify a **non trivial** situation in terms of effective potential but in absence of simple correlations.



RW+quadratic potential model



# ABM model with moving average-based strategies

(V. Alfi, L.P., M. Cristelli, A. Zaccaria >2008)

N players:

$N_F$  fundamentalists

$N_C$  chartists

At each time step, each agent can change its strategy with probabilities

$$P_{CF} \sim \left(K + \frac{N_F}{N}\right) \exp(\gamma|p - p_F|) \quad P_{FC} \sim \left(K + \frac{N_C}{N}\right) \exp\left(\frac{b|p - p_M|}{M - 1}\right)$$

Price formation (price change related to excess demand; liquidity problem)

$$p(t + 1) = p(t) + \sigma\xi + b \frac{p(t) - p_M(t)}{M - 1} N_C + \gamma(p_f - p) N_F$$

# Switching between F and C strategies

Origin of the Finite size effects

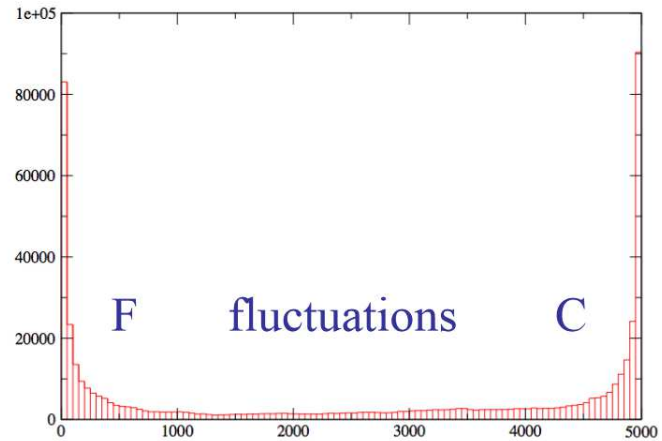
$$N = N_F + N_C$$

$$P_{C \rightarrow F} = \beta \left( K + \frac{N_F}{N} \right) \quad P_{F \rightarrow C} = \beta \left( K + \frac{N_C}{N} \right)$$

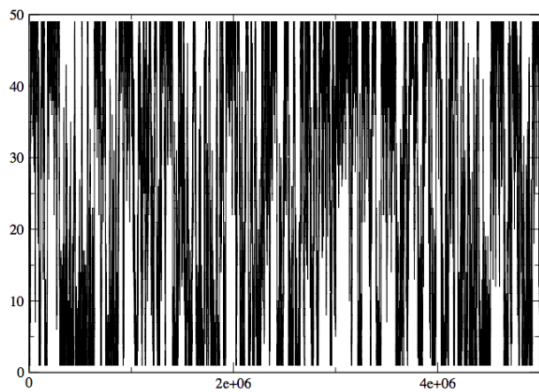
$$x = \frac{N_F - N_C}{N}$$

$$P_e(x) = \frac{1}{L} \frac{1}{1 - x^2}$$

Kirman 1993; Alfarano&Lux 2006

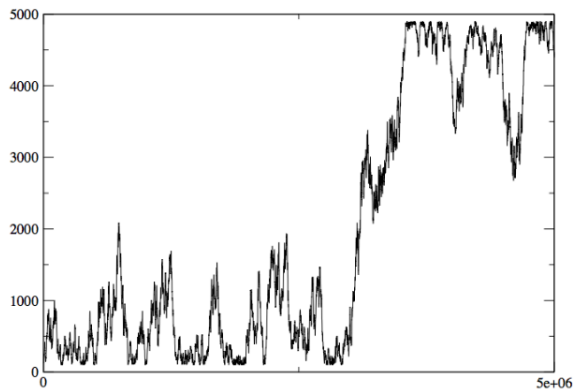


Too fast fluctuations



N=50

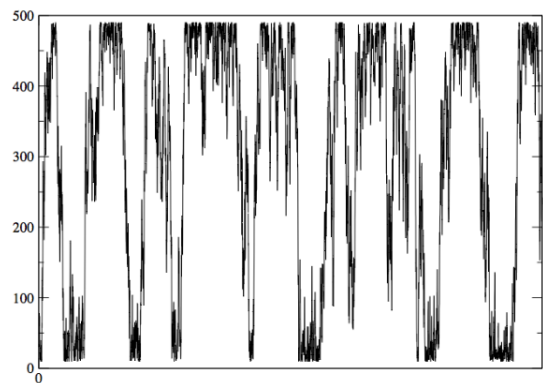
Too low fluctuations



N=5000

$$N_c \quad \beta = 0.005$$

Intermittency OK (Stylized Facts)



N=500

NB: For N diverging fluctuations are suppressed. Therefore Stylized Facts correspond to finite size effects

Asymmetric case: Basically Fundamentalists  
with bubbles due to Chartists

(assumption of asymptotic stability:  
not quite realistic in these times)

If the transition probabilities are symmetric the equilibrium distribution is bimodal or unimodal depending on the parameters

With asymmetric transition probabilities the scenario is richer

$$P_{CF} = \left( a_1 + b_1 \frac{N_F}{N} \right) \quad P_{FC} = \left( a_2 + b_2 \frac{N_C}{N} \right)$$



TENDENCY TO FUNDAMENTALISM:  
INSTITUTIONAL INVESTORS IN QUIET TIMES

$$P_{CF} = B(1 + \delta)\left(K + \frac{N_F}{N}\right) \qquad K = \frac{1}{3N}$$

$$P_{FC} = B(1 - \delta)\left(K + \frac{N_C}{N}\right) \qquad \text{bimodal region}$$

$$P_{eq} \sim \nu^{r(1-\delta)-1} (1 - \nu)^{r(1+\delta)-1} \exp(-\delta\nu N)$$

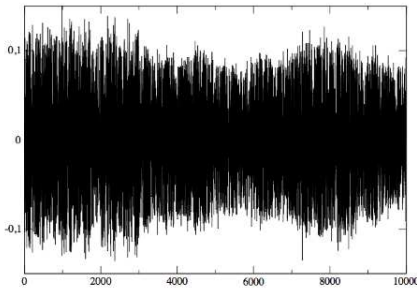
$$\nu = \frac{N_C}{N} \qquad \text{relative number of chartists}$$

For large value of N chartists are suppressed

## N dependence of price fluctuations:

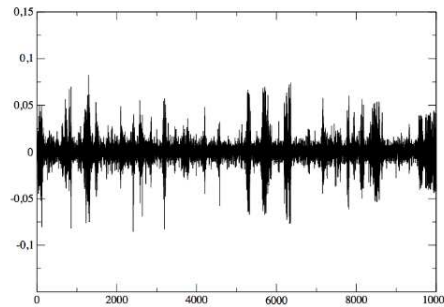
### Switching effect between Fundamentalists and Chartists

N = 50



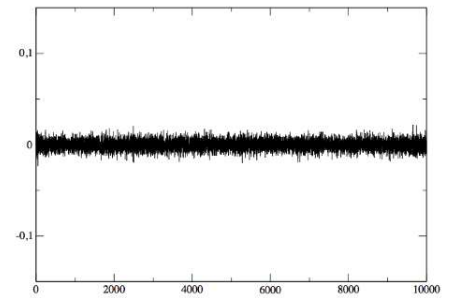
Changes of opinion  
are too fast

N=500



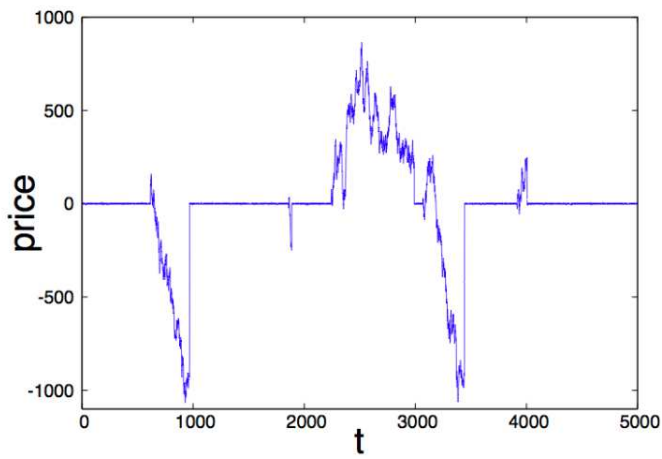
Intermittent behavior: OK  
(Lux, Stauffer 2000)

N 5000



Too stable and dominated  
by fundamentalists

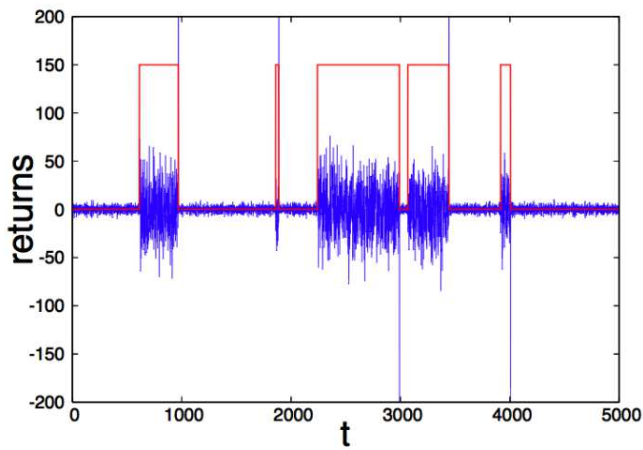
Puzzle: Interesting fluctuations appear at finite N and disappear for infinite N; unlike Critical Phenomena in Physics



$N=1$   
 $M=10$   
 $b=5 \cdot 10^{-4}$   
 $K=0.05$   
 $B=1$   
 $g=0.1$   
 $s=1$

$(Pf = 0)$

**NB: even a single agent can show some intermittency**



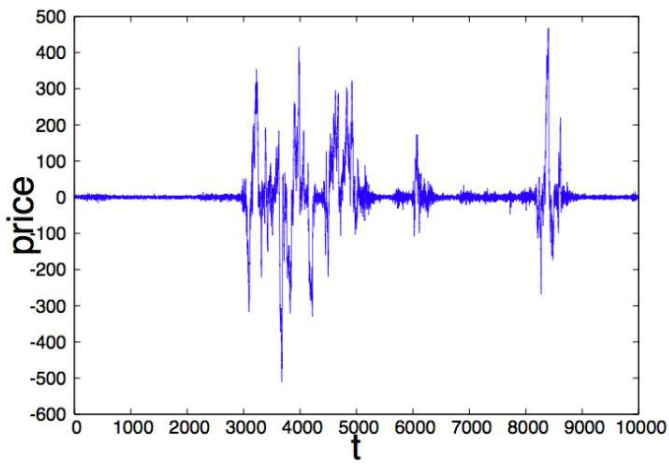
Bursts of price fluctuations

appear spontaneously

and are clearly due to

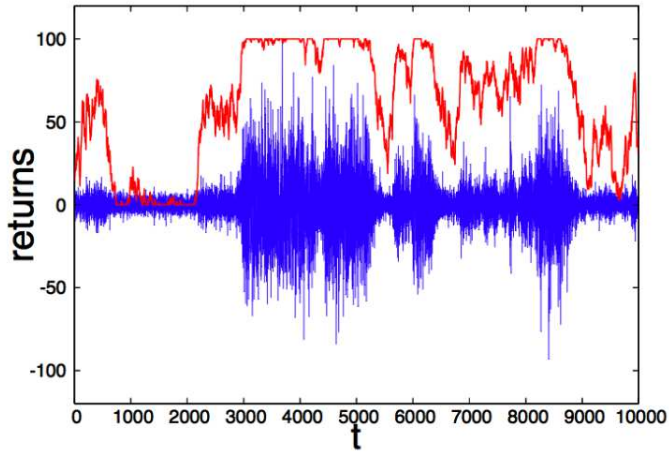
Chartists' dynamics

(Possibility of analytical studies)



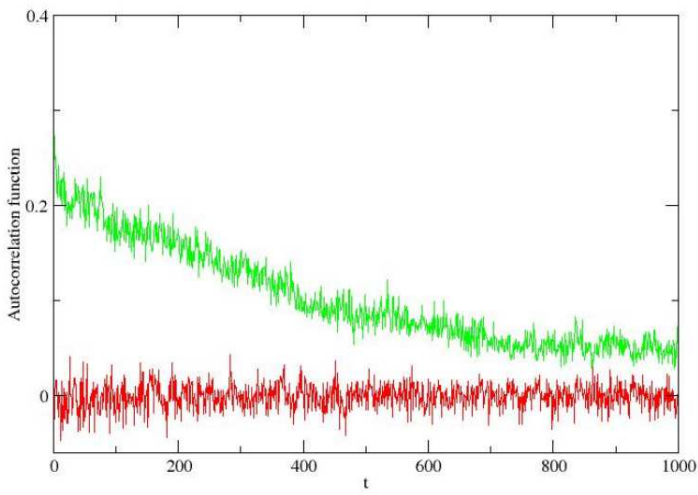
$N=100$   
 $M=10$   
 $b=1 \cdot 10^{-3}$   
 $K=0.002$   
 $B=1$   
 $g=0.1$   
 $s=1$

$N=100$

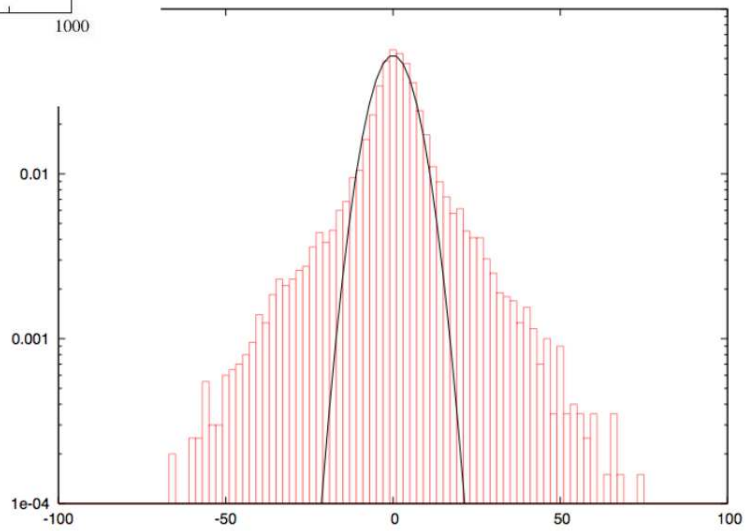


NB: All the parametraters are  
 now in full control  
BUT fine tuning is always  
 necessary

Autocorrelation  
functions of returns  
and square returns  
NB: SF arise from  
Finite Size Effects



Probability density  
function of  
price-returns



# What is really N or N\*?

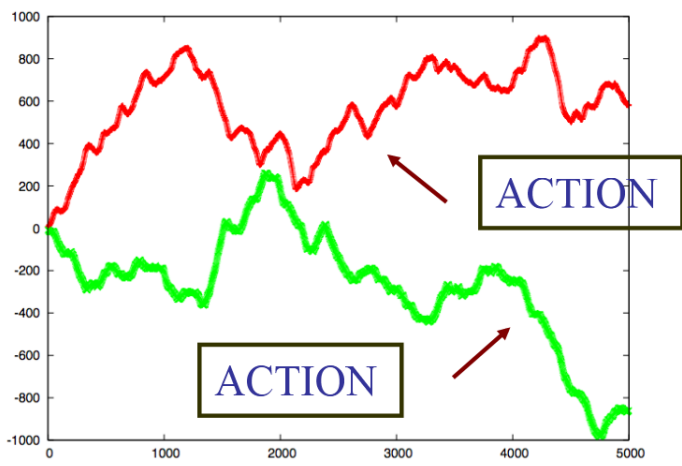
- In general the number of agent N is fixed in the Agent Models  
This idea originates probably from Stat Phys but it is rather unrealistic for trading

## Nonstationarity, route to Self-organization

- NB: Strongly correlated portfolios lead to an effective reduction of N\* and therefore towards less stable situations.  
Comments by M. Gordy, G. Barone-Adesi, M. Marsili  
M. Buchanan (hedge funds with similar portfolio)

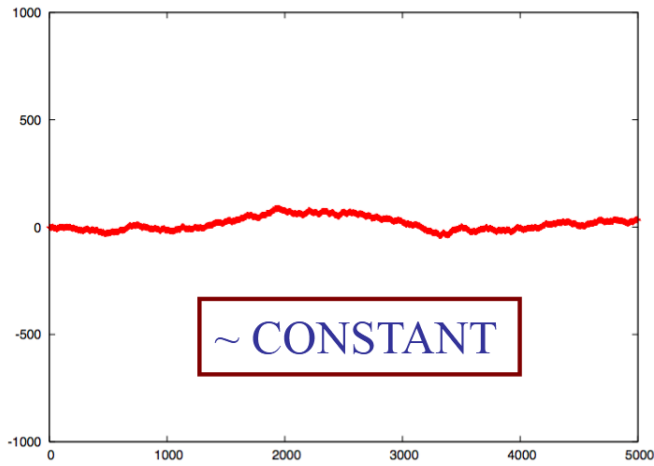
Important: Estimate N\* from real market data

In the model the N agents may influence by the herding rules, but if they a priori behave the same this decreases N (network, leaders, gurus, media, panic etc.)



$N_C$  and  $N_F$  detect interesting signals and are stimulated to take an action

In this case  $N^*$  increases



In this case little action is stimulated

$N^*$  drops

ACTION  $\longrightarrow$  INCREASE OF  $N^*$

This resembles the GARCH phenomenology but

At a microscopic level

$$\sigma(t + 1) = f(\sigma(t); \Delta p(t))$$

Following our concept:

action  $\Delta p(t) \rightarrow$  increase of  $N^* \rightarrow$

increase of  $\sigma \rightarrow$  increase of  $|\Delta p(t + 1)|$



Therefore there is a multiplicative nature of correlations which leads to a persistence in the value of  $\rho$  (high or low).



CONCEPTUAL FRAMEWORK FOR FAT TAILS  
AND VOLATILITY CLUSTERING  
(NONSTATIONARITY)  
MICROSCOPIC AGENT-LIKE INTERPRETATION  
OF ARCH-GARCH PHENOMENOLOGY

## Why no arbitrage ?

Any action  $\longrightarrow$   $\square(N^*)$  increases

but price trend is much more complex

$$\Delta p(t + 1) = f(N^*; N_c; N_F; p_M(t); p_F)$$

Therefore: much more information is crucial for the sign of the price return

# Towards Self-organization

## Asymmetric case: Basically Fundamentalists with bubbles due to Chartists

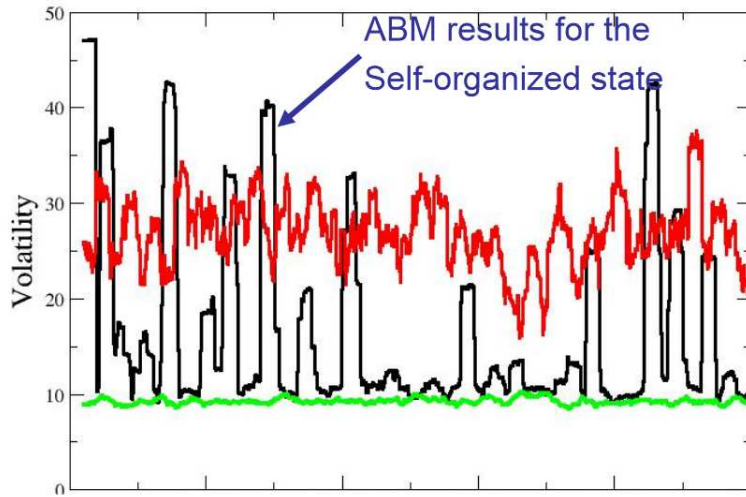
(not quite realistic in these times)

If the transition probabilities are symmetric the equilibrium distribution is bimodal or unimodal depending on the parameters

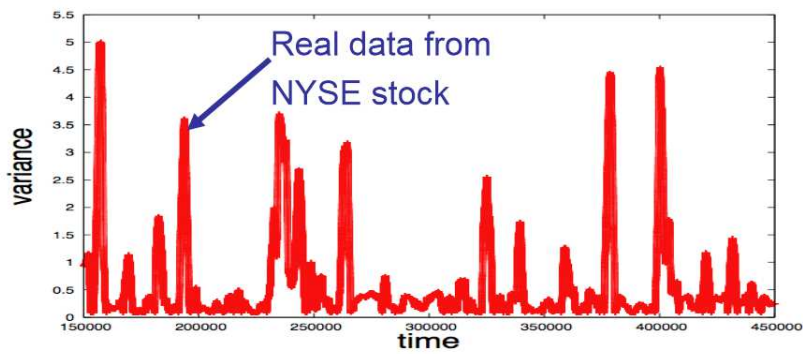
With asymmetric transition probabilities the scenario is richer

$$P_{CF} = \left( a_1 + b_1 \frac{N_F}{N} \right) \quad P_{FC} = \left( a_2 + b_2 \frac{N_C}{N} \right)$$

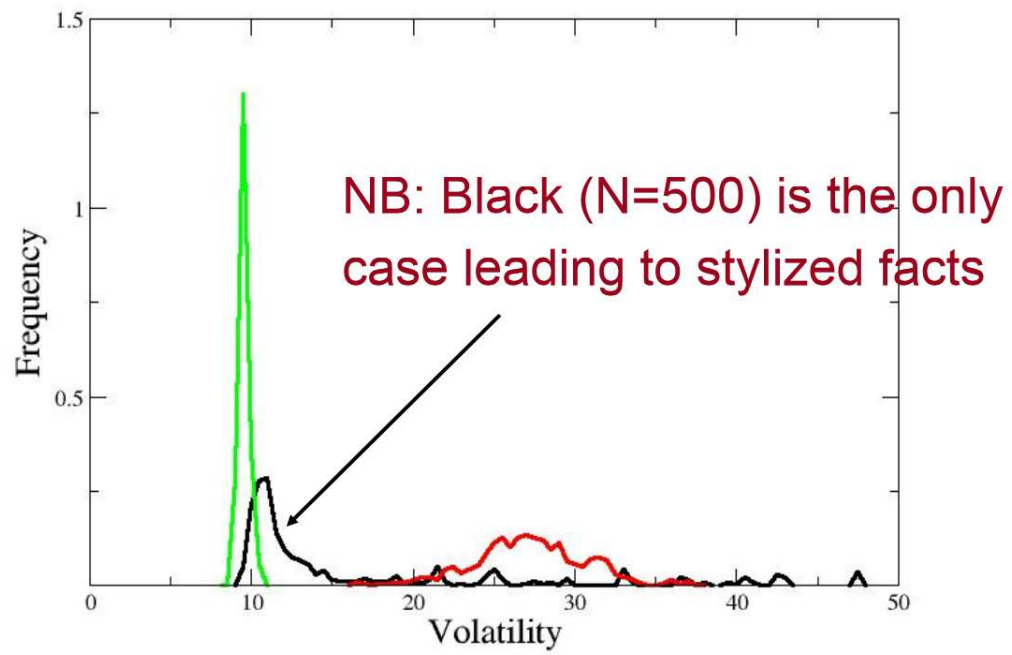
(red N=50; black N=500; green N=5000)



NB: largest peaks  
Correspond to the  
Intermediate case.  
It takes some stability  
in the C state to  
develop a bubble



(red N=50; black N=500; green N=5000)



# Basic criterion for Self-Organization:

- Agents decide whether trading (or not) depending on the price movements they observe  
(Competition with other investments in the Global Network)
- Stable prices: Less trading
- Large action (price movements): More trading  
(Euphoria, bubbles, panic, crashes)

Caution: some agents may prefer a stable market and be scared by fluctuations. This would require an analysis of different time scales and, in any case, these agents certainly do not produce the Stylized Facts

Each agent calculate the price-volatility on the previous T steps

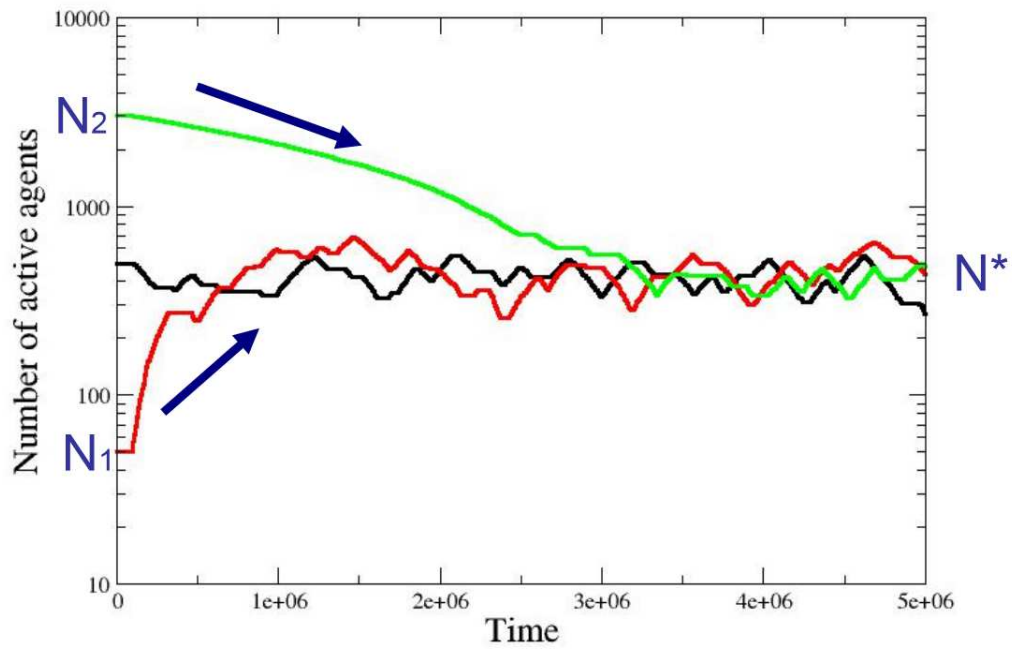
$$\sigma(t, T) = \frac{1}{T - 1} \sum_{i=t}^{t-T} (p_i - \bar{p})^2$$

On the basis of the calculated volatility each agent has a probability to enter/leave the market if the volatility is above/under a certain threshold

$$\sigma(t, T) > \Theta_{in}$$

$$\sigma(t, T) < \Theta_{out}$$

Self-Organization in action: Different starting  $N$  (50, 500, 3000) evolve and finally converge to the Quasi-critical state ( $N=500$ ) which corresponds to the Stylized Facts

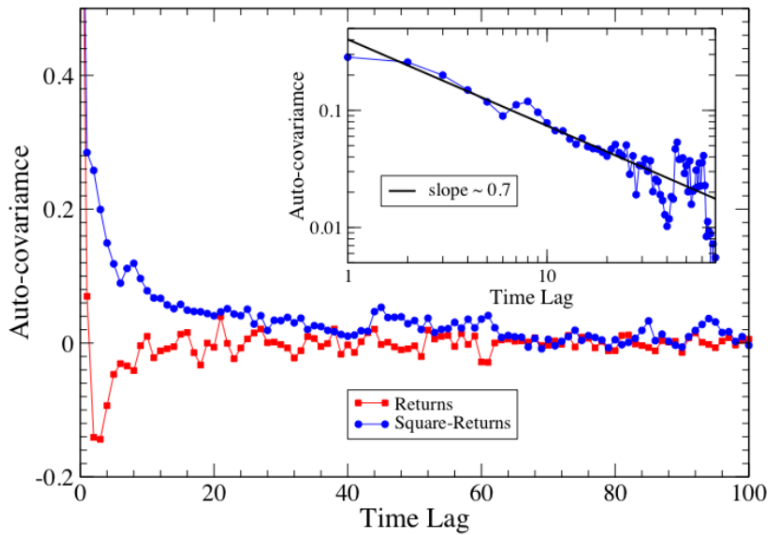




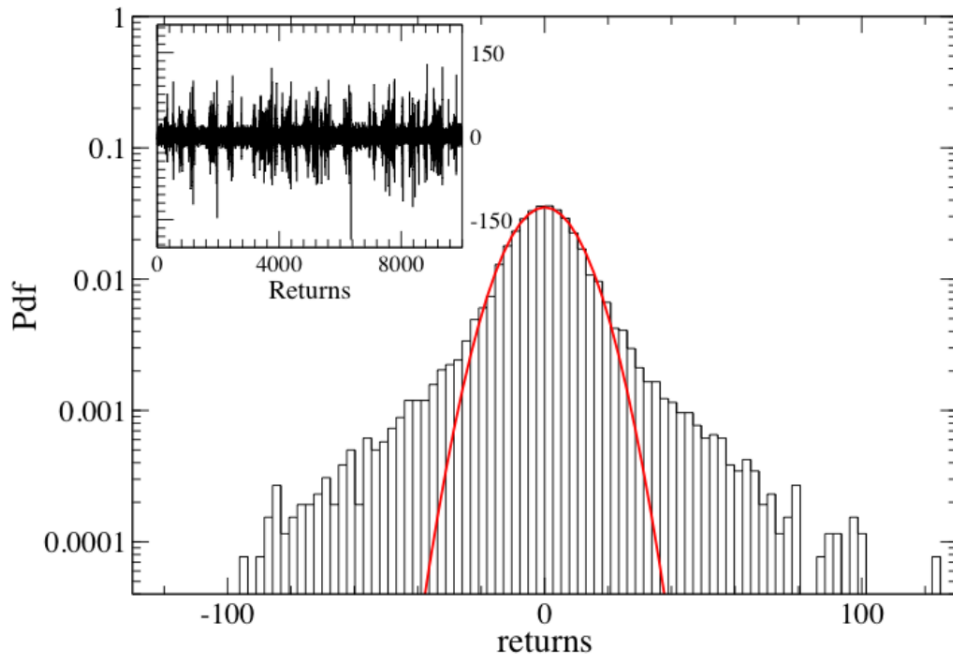
Linear dynamics;  $N = 500$ ;

Heterogeneity with respect to their time horizon

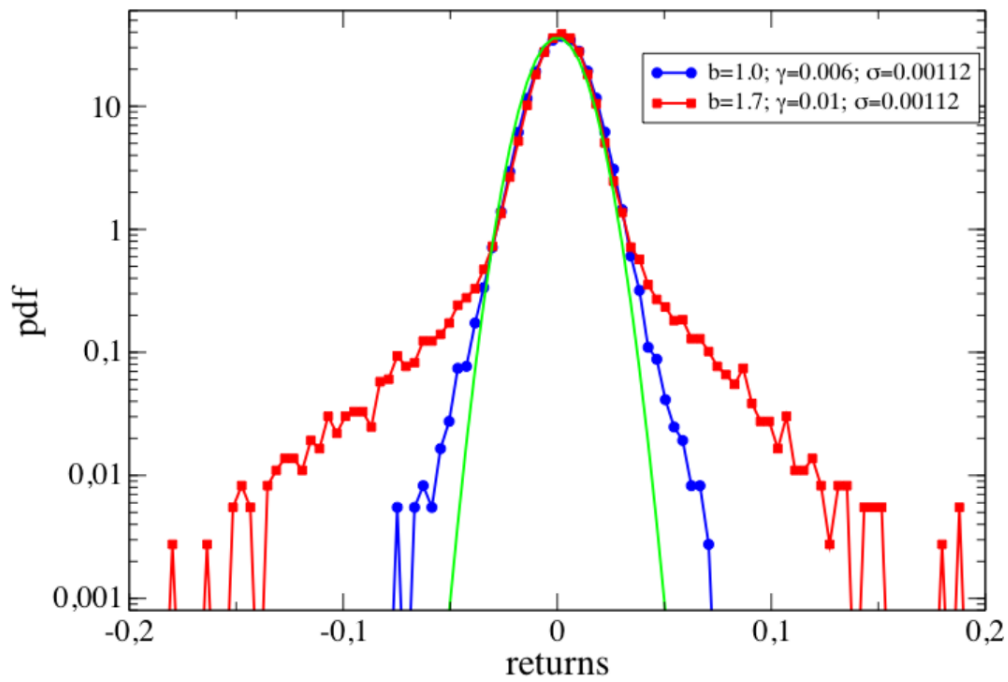
Volatility clustering is decreased because the behavior is less coherent



Apparent power law behavior but no fundamental critical phenomenon

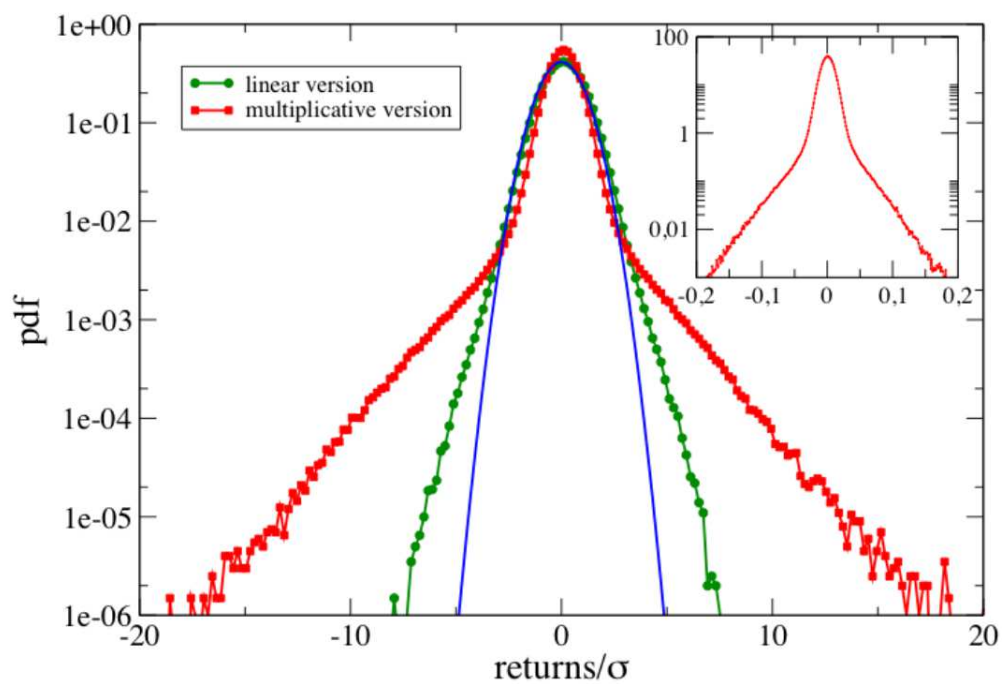


Multiplicative dynamics: Extreme sensitivity to parameter region. Slightly different parameters lead to very different Fat Tails



## Comparison between linear and multiplicative dynamics

Fat Tails are usually larger for the Multiplicative case



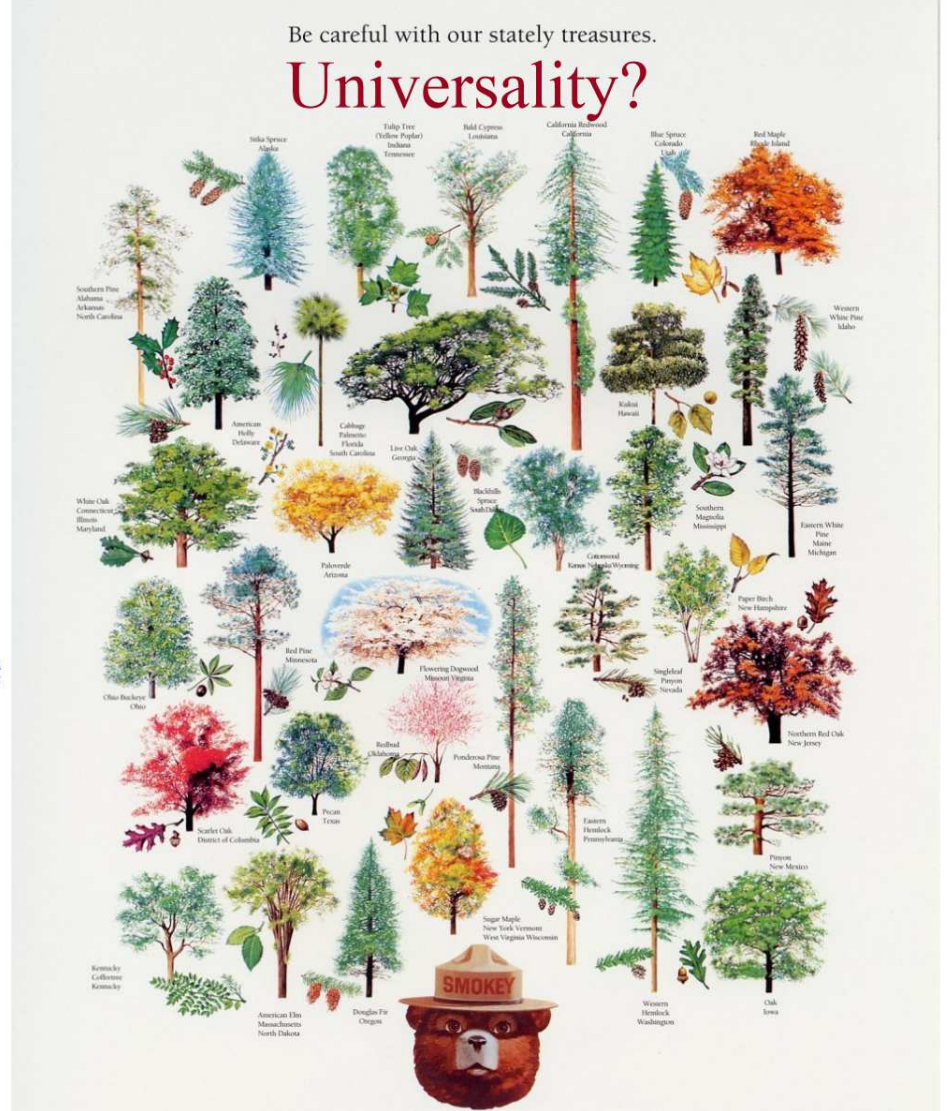
# Power laws and universality?

- **Herding**: naturally leads to population switching (i.e. F vs C)  
For a given N and a single time horizon this leads to a characteristic time scale.  
Distribution of trading horizons leads to many time scales
- **Nonstationarity**: key element for the Self-organization  
traders may decide NOT to play or to  
play variable amounts of shares (volume)  
Switching situation: Finite Size Effects
- **Strong deviations from gaussian behavior** but not necessarily  
critical with universal power laws.

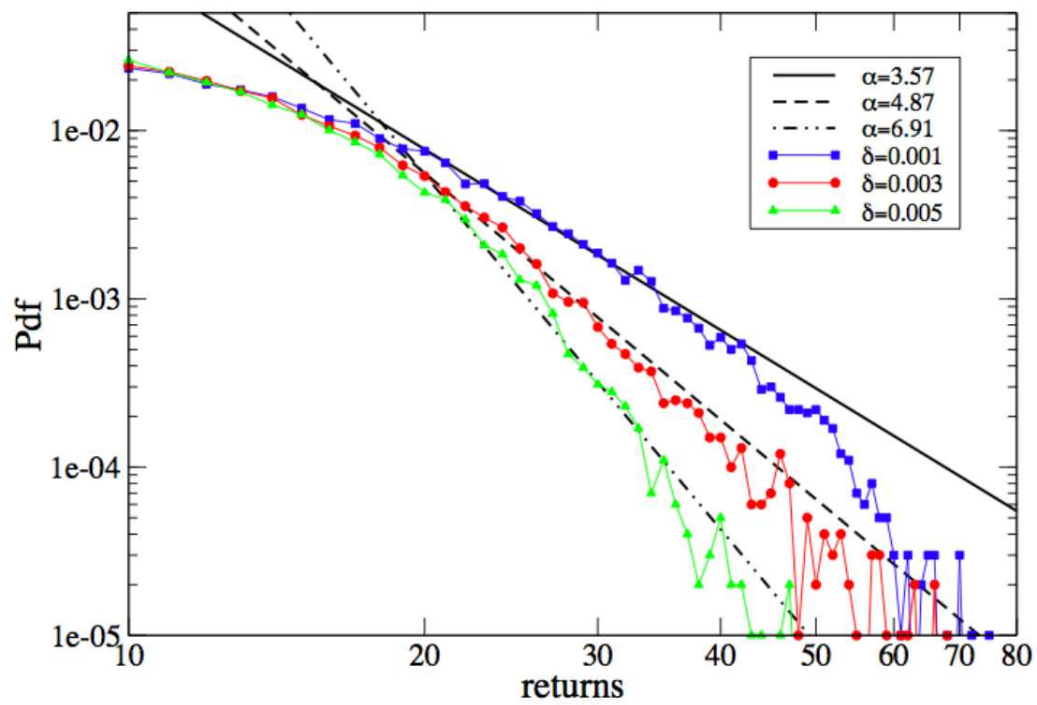
NB. Different opinions about data analysis:

HE Stanley; R. Cont; J. Kertesz; D.Sornette; C. Tsallis ...

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.

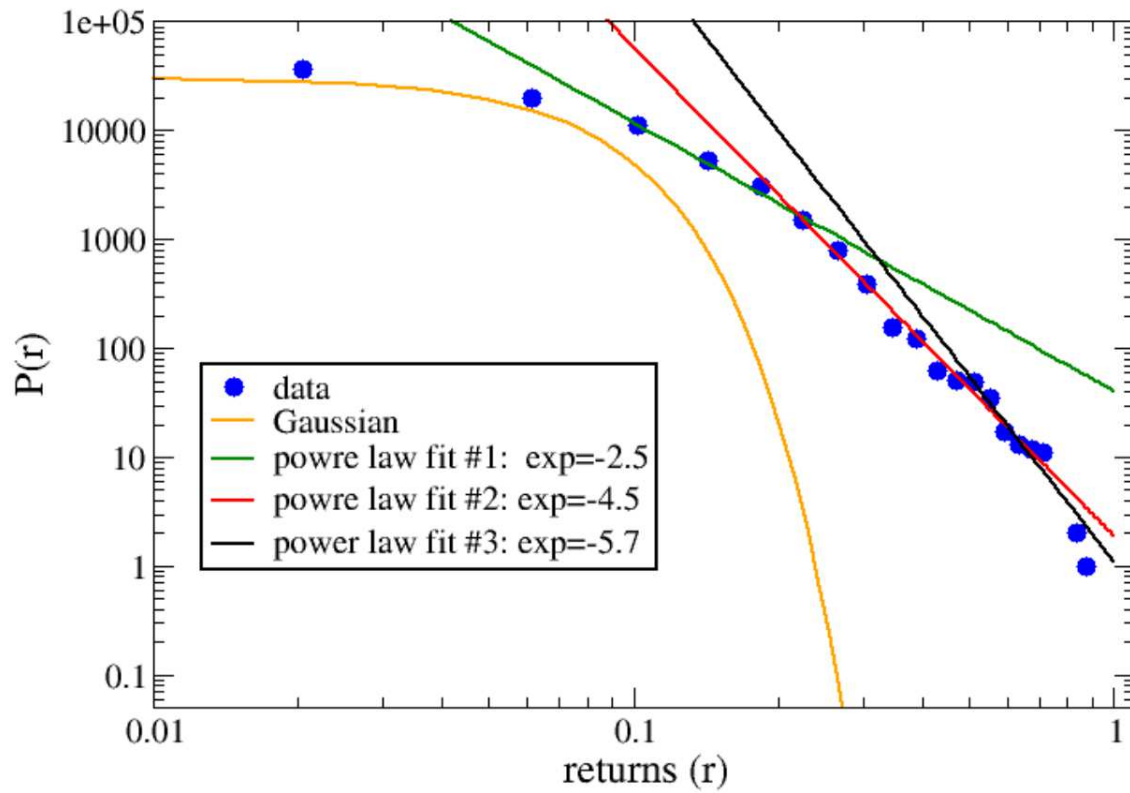


Fat Tail effective exponents as a function of model properties:  
More Chartists lead to larger Tails  
Nonuniversality leads to a richer interpretation of data

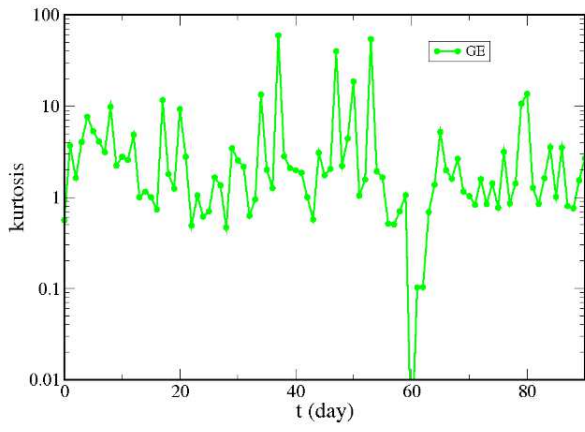


Real data: difficult to define a single exponent

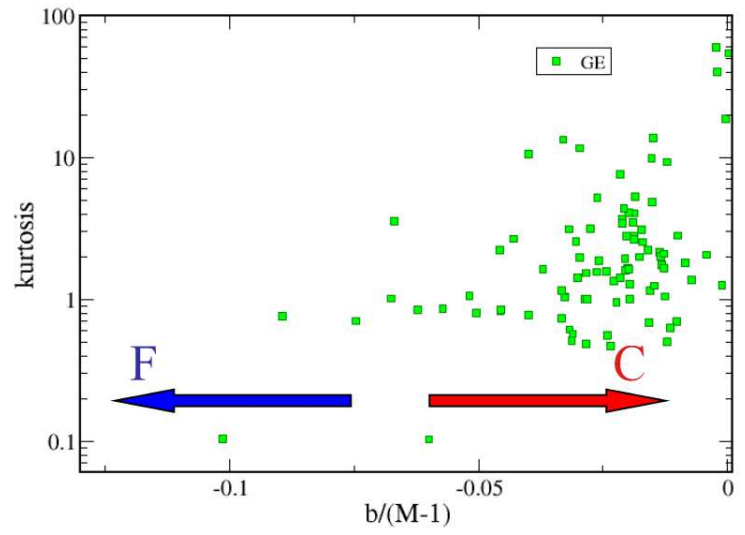
Alternative for non gaussianity: Kurthosis







Kurthosis vs Market Sentiment:  
 Chartists or Fundamentalists  
 Stabilization vs destabilization  
 not optimist vs pessimist



Spanish Stock market members have identifications codes

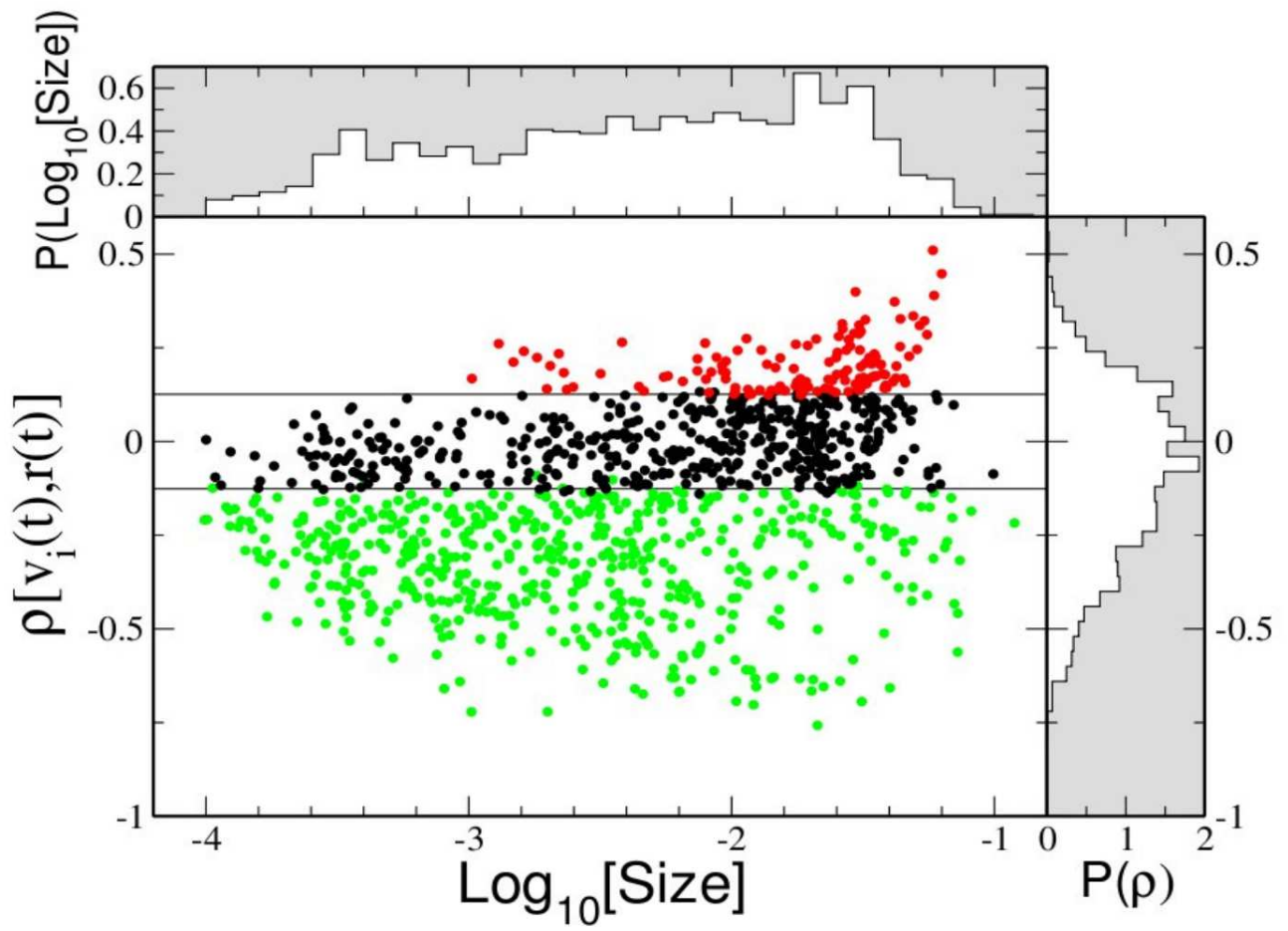
Four highly capitalized stocks and the most active firms (at last 200 trading days per year) are considered. The number of active firms ranges from 54 to 82

The daily inventory variation (the value exchanged as a buyer minus the value exchanged as a seller in a given time interval) is investigated (2001-2004)□

The authors find a statistically significant correlation between the inventory variation and the price returns and hypthesize a linear relation

$$v_i(t) = \gamma_i r(t) + \varepsilon_i(t)$$

The sign of the correlation is a feature of the behavior of the firm. If positive, it is “trending”, if negative “reversing”



Specialization and herding behavior of trading firms in a financial market,  
 Lillo, Moro, Vaglica and Mantegna New J. Phys. 10 No 4 (April 2008) 043019

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	2001	2002	2003	2004
Reversing	43	39	42	37
Uncategorized	28	31	31	29
Trending	11	10	8	6
Total	82	80	81	72

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Specialization and herding behavior of trading firms in a financial market,  
Lillo,Moro,Vaglica and Mantegna New J. Phys. 10 No 4 (April 2008) 043019

ABM  
ideal

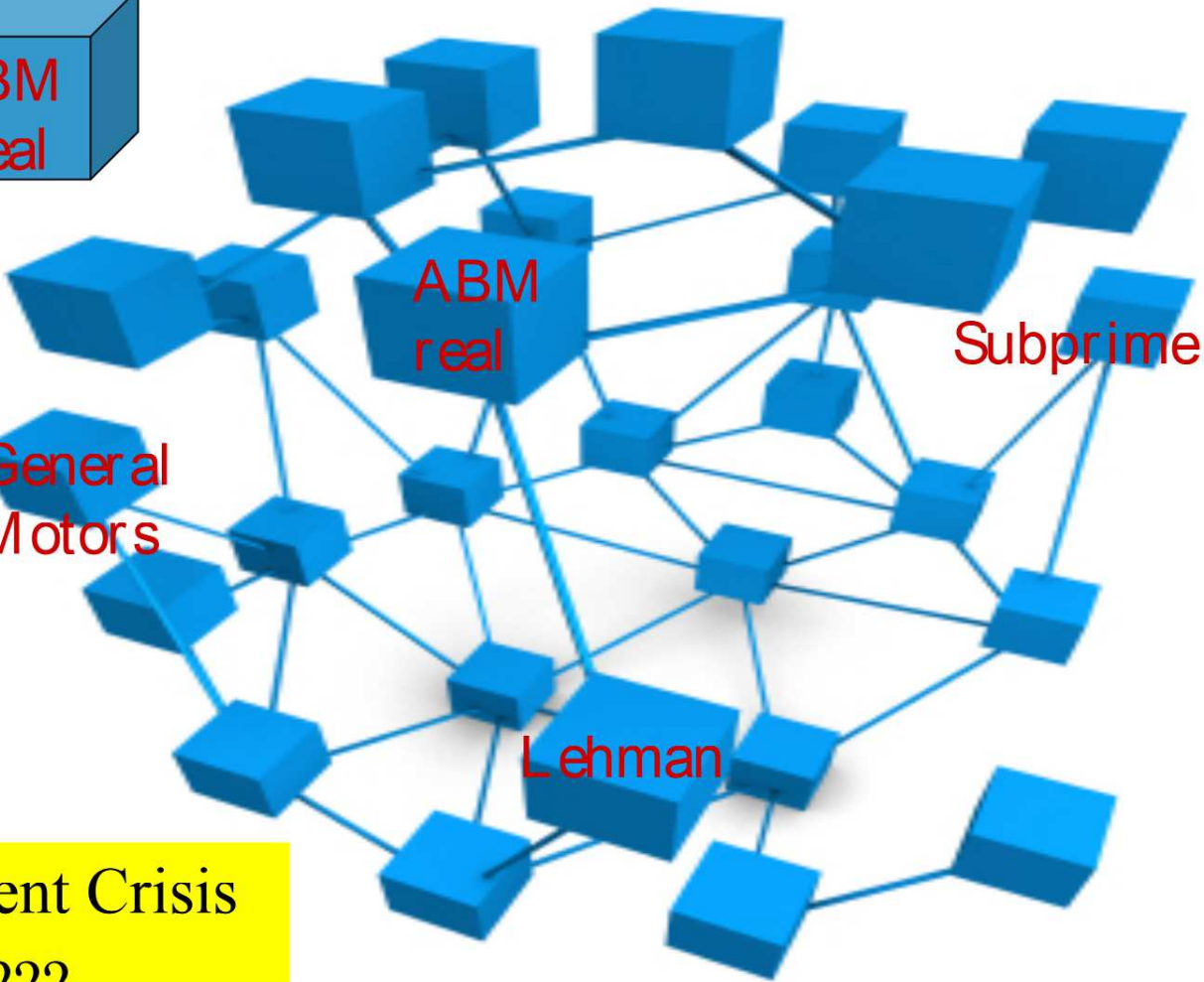
General  
Motors

ABM  
real

Subprime

Lehman

Recent Crisis  
Pf=???



# ABM + Environment

BASIC ANSATZ

Fundamentalists dominate in the long run (?)

$t \rightarrow \infty$  Basic Stability

But in a complete model this may require evolution and adaptation for all possible instabilities

External fluctuations affect all properties but mostly the estimate of the Fundamental Price

$$\Delta p \sim 3\% \quad \text{per day}$$

$$\Delta p \gg \Delta p_f$$

Different Situation:  $p_f \pm \Delta p_f$

if

$$\Delta p_f > \Delta^*$$

Fundamentalists are discouraged

In a global crisis  $N^*$  is strongly suppressed

# Summary from ABM:

Globalization - Social interactions - Network:  
New opportunities and New Risks.

- Feedback, amplification, nonlinearity
- Fat tails and Stylized Facts arise from finite size effect  
Nonuniversality leads to richer analysis tool
- General sentiment vs direct links, effective  $N^*$
- Network oriented approach - New indicators for a systemic risk approach - Microscopic data and network of mutual exposure. Contagion - correlations.
- Trust: definition in math terms and more attention to people's behavior, herding etc.
- More scientific oriented tests - less ideology











