Complexity in economics and finance

D. O. Cajueiro[1,2]

[1]Department of Economics, Universidade de Brasília.

[2]National Institute of Science and Technology for Complex Systems.

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Economics and finance systems are complex!

Why?

- The presence of feedback: These systems depend and respond to the past in a non-trivial way
- Non-stationarity: The statistical and dynamic properties of these systems may chance over time
- Many interacting agents competing with each other [this is totally different from the usual hypothesis of representative agent]
- Adaptation: The agents adapt their behavior over time
- Evolution: All agents evolve over time

☺ Johnson, N. F., Jefferies, P. and Hui, P. M. Financial Market Complexity: What Physics Can Tell Us About Market Behaviour. Oxford University Press, 2003.

Complexity in financial and economic time series

What seems to be relevante?

- Long range dependence in financial time series
- Understanding financial assets and derivatives dynamics
- Forecasting financial and economic data
- Forecasting switching points in financial time series

The presence of long range dependence in financial time series

Most works try to detect the presence of LRD in FTS!
But people already know that there is weak evidence of LRD in return series and strong evidence of LRD in volatility FTS.
We also know that the evidence of LRD usually increases in underdeveloped markets!

The presence of long range dependence in financial time series

Are still interesting topics to be investigated?
Yes!

- Which are the sources of LRD in FTS? What is determinant for detecting the presence of LRD in financial time series?
- LRD is a kind of spurious regression? Is this only a consequence of switchings that take place in the FTS dynamics?
- The evaluation of LRD over time seems to be more interesting than statical measures of LRD
- LRD? So what?? Is it possible to build trade rules using information based on the Hurst exponent?

The presence of long range dependence in financial time series

An example:

☺ Cajueiro, D. O. and Tabak, B. M. Possible causes of long-range dependence in the Brazilian stock market. Phys. A 635-645, 2005. [ISI 7]

We have found evidence of statistically significant rank correlation between specific variables [Market capitalization and Return on Equity] of the of the Brazilian firms which subscribe stocks amount of LRD present in these stocks.

Another interesting reference:

☺ Cajueiro, D. O. and Tabak, B. M. The Hurst exponent over time: testing the assertion that emerging markets are becoming more efficient. Phys. A 336, 521-537, 2004. [ISI 52]

Financial assets and derivatives dynamics

Usual view: ☹ Stochastic models in economics and finance are only based on the normal distributions. This is not true! There are several models with different distributions. [For instance, with Levy distributions. Very common for mathematical economists]

However, there is still place for contributions:

☺ Borland, L. Option pricing formulas based on a non-Gaussian stock price model PRL 89, 098701, 2002. [ISI 49]
☺ Cortines, A. A. G. Riera, R. Anteneodo, C. From short to fat tails in financial markets: a unified description. European Physical Journal B, 60, 385-389, 2007. [ISI 2]

Forecasting in economics and finance

Characterizing FTS is interesting, but forecasting FTS is much more interesting and difficulty! Unfortunately, most econophysics works still focus on the former point.
We are talking about

- Out of sample forecasting
- Models that can beat the random walk model [models that are better than the martingale model] This is not easy!
- If forecasts are possible, random walk tests should reject the hypothesis of random walk model

Forecasting in economics and finance

An interesting reference:
☺ Lo, A. W. Foundations of technical analysis: Computational algorithms, statistical inference, and empirical implementation. Journal of Finance 55, 1705-1765, 2000. [ISI 75]

An out of date, but still interesting reference:
☺ Campbell, J. Y. Lo, A. W. and MacKinlay A. C. Econometrics of financial markets. Princeton University Press, 1996.

Forecasting switching points in financial time series

This is the real thing!

There are at least two different approaches to it:

- The usual financial econometrics
- The Sornette's approach

Forecasting switching points in financial time series

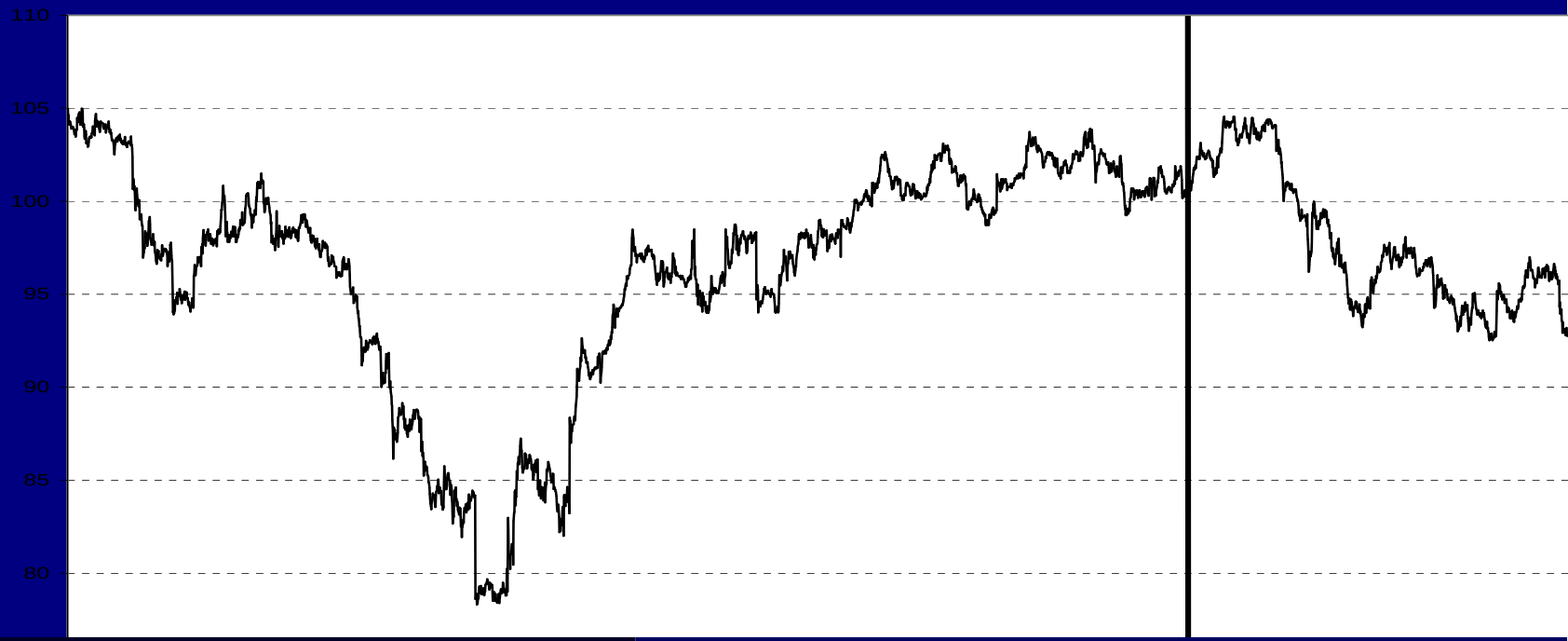
The Sornette's approach:
The idea is to estimate

$$h(t) \approx A + B(t_c - t)^{\beta} + C(t_c - t)^{\beta} \cos(\omega \log(t_c - t) + \phi)$$

where t_c is the most relevante parameter – the crash time.

Forecasting switching points in financial time series

An example of Sornette's approach working: Petr3



Forecasting switching points in financial time series

- It is clear that it only works for endogenous bubbles... But for all?
- How robust is this method?

Forecasting switching points in financial time series

Some interesting references:

☺ Sornette, D. Why Stock Markets Crash: Critical Events in Complex Financial Systems, Princeton University Press, 2004.

☺ Scheffer, M. Critical Transitions in Nature and Society. Princeton University Press, 2009.

☺ Cajueiro, D. O., Tabak, B. M. and Werneck, F. K. Can we predict crashes? The case of the Brazilian stock market. Phys. A, 388, 1603-1609, 2009.

Agent based models

A nice way for modeling heterogeneity economics and finance.
However, be careful! This is not a playground for computer nerds!
Interesting references:

☺ LeBaron, B. Complex adaptive systems: An introduction to computational models of social life Journal of Economic Literature 46, 427-429, 2008.

☺ Kirman, A. Artificial Markets: Rationality and Organisation. Complexity and Artificial Markets Book Series: Lecture Notes in Economics and Mathematical Systems 195-234, 2008.

Agent based models

☺ LeBaron, B. and Tesfatsion, L. Modeling macroeconomies as open-ended dynamic systems of interacting agents American Economic Review 98, 246-250, 2008. [ISI 2]

☺ Bouchaud, J. P. Economics needs a scientific revolution. Nature 455, 1181 - 1130, 2008.

☺ Colander, D., Howitt, P. Kirman, A., Leijonhufvud, A., Mehrling, P. Beyond DSGE models: Toward an empirically based macroeconomics. American Economic Review 98, 236-240, 2008. [ISI 1]

Agent based models

☺ Advantages:

- The introduction of heterogeneity in finance and economics
- Freedom on the definition of the evolution rules
- One may avoid unbounded rationality and representative agent models

Agent based models

☹ Disadvantages:

- Simulation does not ensure stable behavior of the agent. [I mean even if you find that an agent presents a given behavior after 1000 simulation, in general, it does not mean that in the next one, the agent will have the same behavior.]

The minority game

- This is one of the simplest complex systems introduced in order to study the dynamics and the collective behavior of populations of agents who compete for limited resources.
- It is the computational version of the El-Farol Bar Problem.

The minority game

The Bar Problem

"$N = 101$ people decide independently each week whether to go to a bar. Space is limited and the evening is enjoyable if fewer than 50 percent of the possible 101 are present. Therefore, a person *goes* to the bar, if expects fewer than 50 to show up ou *stays at home* if he expects more than 50 to go."

If it were possible to formulate a correct model based on the past weeks data, then either all persons would go to the bar or all persons would stay at home. Therefore, there is no possible solution!

The minority game

It can be implemented as follows:

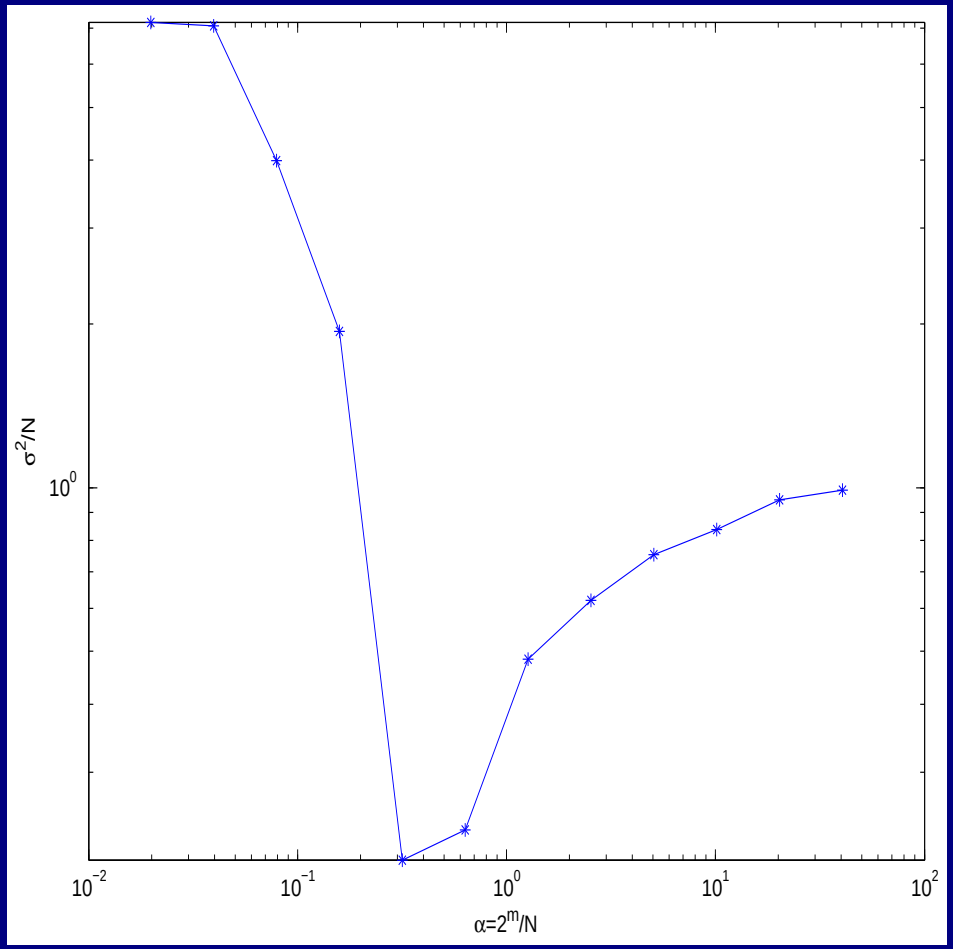
- At a given instant of time, an agent who belongs to a population of size N chooses between two opposing actions, namely $a = \pm 1$
- The agent chooses his next action based on a strategy, which is a mapping that defines the action to be taken as a function of the global information, which is the sequence of the last M outcomes of the game
- The strategy books are randomly assigned to each agent before the beginning of the game.
- We use reinforcement learning to choose the best strategy in each date.

Minority games

One of its most surprising properties is summarized by plotting the ratio σ^2/N as a function of $\alpha = 2^M/N$:

- For small values of α, the agents would perform worse than if they had taken purely random decisions.
- For large values of α, the agents' performance approaches the random decision.
- There is a critical value of $\alpha = \alpha_c$ where the resources of the game are used in the best way possible.
- At α_c, the ratio σ^2/N assumes its minimal value, suggesting a phase transition from the so-called low-M to the high-M phase.

Minority games



Minority games

There are also analytical results for the minority game.

Minority games

Some useful applications:

- Financial markets
- Choices of vocations
- Market entry decisions of firms
- Auctions of used cars
- Definition of the concept of intelligence

Minority games

Interesting references:

☺ Arthur, W. B. Inductive reasoning and bounded rationality. American Economic Review, v. 84, n. 2, p. 406–411, 1994.

☺ Challet, D. and Zhang, Y. C. Emergence of cooperation and organization on an evolutionary game. Physica A 246, p. 407–418, 1997.

☺ Savit, R., Manuca, R. and Riolo, R. Adaptive competition, market efficiency and phase transitions. Physical Review Letters 82, p. 2203–2206, 1999.

☺ Lustosa, B. C. and Cajueiro, D. O. Constrained information minority game: How was the night at El Farol? Phys. A 389, 1230-1238, 2010.

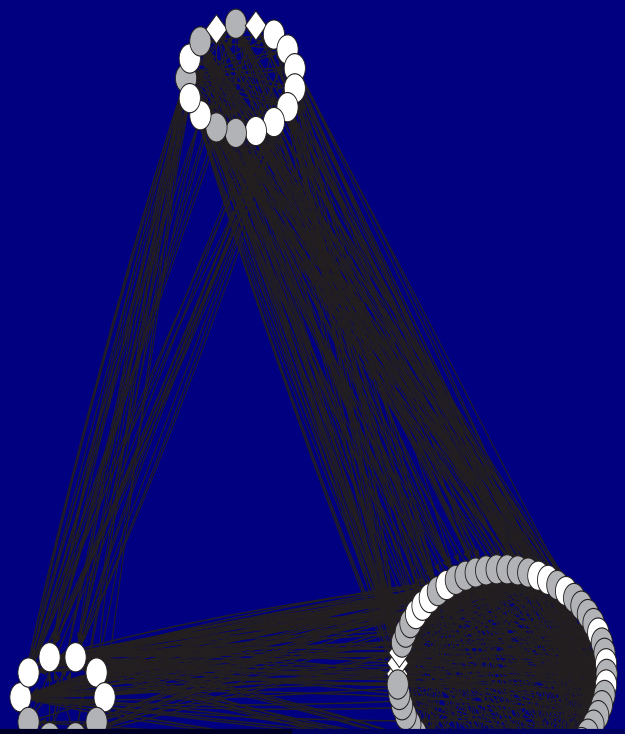
☺ Mello, B. A. and Cajueiro, D. O. Minority games, diversity, cooperativity and the concept of intelligence. Phys. A 387, 557-566, 2008.

Complex economic and financial networks

- The economy reflects a dynamic interaction of a large number of different agents.
- The resulting systemic behavior often shows consequences that are hard to predict.
- We need a more fundamental insight into the system's dynamics and how they can be traced back to the structural properties of the underlying interaction network.

Bank networks

A nice example: The network of the Brazilian interbank market



Bank networks

☺ Cajueiro, D. O. and Tabak, B. M. The role of banks in the Brazilian interbank market: Does bank type matter? Phys. A 387, 27, 6825-6836, 2008. [ISI 2]

- Public banks are the most relevant money centers of the network
- Foreign banks are the most significant borrowers of the market
- Retail and large banks play simultaneously the role of the most important lenders and borrowers of the market

Self-organized criticality in Economic and financial systems

- Are financial markets self-organized systems?
- May self-organized criticality explain economic fluctuations?

I believe that those questions are motivate ones!

Self-organized criticality in economics

Some interesting references:

☺ Scheinkman, J. A. and Woodford, M. Self-organized criticality and economic fluctuations. American Economic Review 84, 417-421, 1994. [ISI 41]

☺ Bartolozzi, M., Leinweber, D. B. and Thomas, A. W. Scale-free avalanche dynamics in the stock market Phys. A 370, 132-139, 2006. [ISI 5]

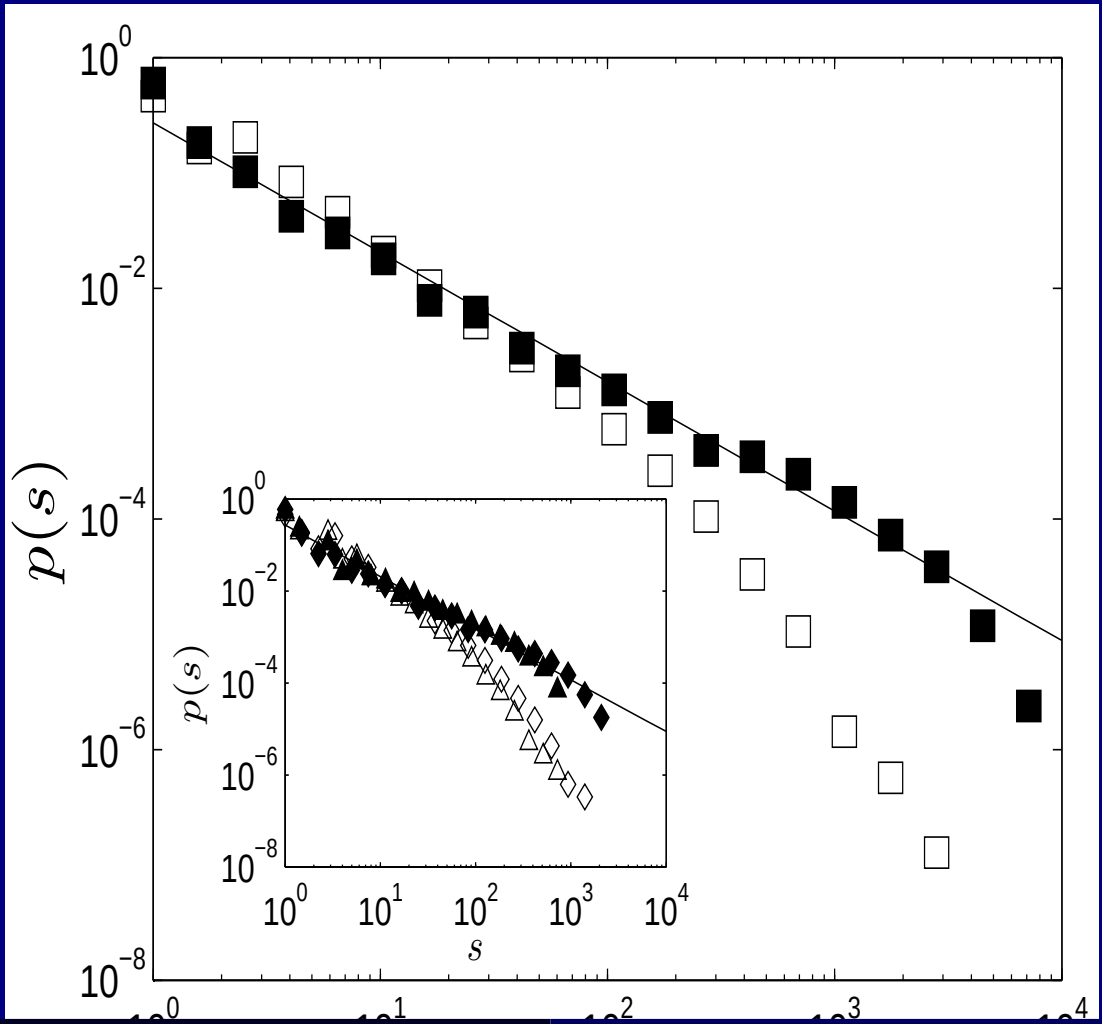
Controlling self-organized criticality

- Self-organized criticality is a characteristic of eternally driven systems that organize themselves without fine parameter tuning.
- The issue considered here is that the process of self-organization of such systems generates events with no characteristic size being very costly to society.
- We have shown that triggering avalanches in sites that are near to be come critical, reduces the probability of very large events, so that energy dissipation occurs most locally.
- Is this really relevant in economics and finance?

Controlling self-organized criticality

The Fed has no explicit mandate under the law to try to contain a stock-market bubble. Indirectly we had the authority to do so, if we believed stock prices were creating inflationary pressures. (...) All the same, we agreed that trying to avoid a bubble was consistent with our mission, and that it was our duty to take the chance. (...) Then we met again on March 25 and raised short-term rates by 0.25 percent (...). Alan Greenspan – The age of turbulence.

Controlling self-organized criticality



Controlling self-organized criticality

The Reference:

☺ Cajueiro, D. O. and Andrade, R. F. S. Controlling self-organized criticality in sandpile models. PRE 81, 015102(R), 2010.

Chaos in economics

Usual view: ☹ Complex dynamics are not relevant in economics since it arises only low discount factors in dynamic programming problems.
This is not true! We have shown for a stochastic dynamic programming problem that complex dynamics may arise for any discount factor.

☺ Cajueiro, D. O. and Maldonado, W. L. Role of optimization in the human dynamics of task execution. PRE 77, 035101, 2008.

Final remarks

Be happy! ☺

If you believe that there is some kind of optimization principle behind individual agents' choices. Then,

EVERYTHING IS GOING TO BE OK!!