Athens and Lisbon Stock Markets: A thermodynamic approach

A.GKRANAS, V.L.RENDOUMIS, H.M.POLATOGLOU
Physics Department
Aristotle University of Thessaloniki
Thessaloniki GR-54124
Greece

Abstract: - In this work, we present the results of our analysis in the stock markets of Greece and Portugal. We recognize exponential laws at both Athens Stock Exchange General Index (GD) and Lisbon's Main Index. This fact stimulates us to apply formalisms taken from physics about the study of macroscopic properties. Especially, we introduce the implication of Newton's law of cooling on these markets. The satisfying fit leads us to express a thermodynamic approach, in our effort to understand such complex behaviors.

Keywords: - econophysics, Athens Stock Exchange, Lisbon Stock Exchange, Newton's cooling law.

1 Introduction

A lot of things have changed in economics in the last 15 years. Quantitative research is now the rule and not the exception as quants, quantitative analysts, often with interdisciplinary background are day by day more and more important in financial institutions and banking foundations. In these recent years a lot of scientists from the field of physics started to study social systems and mostly systems of economy trying to apply methods and formalisms developed for years in their field. This effort was successful, since now days direct access to high-frequency data (on the scale of seconds) not only for stocks, currencies or interest rates, but also for more exotic markets such as option markets, energy markets, weather derivatives, etc. is the rule. So, any statistical model, or theoretical idea, can and must be tested against available data.

Economic complex systems, can be surely studied by a physicist. Logic and simplicity weren't always the rule followed by the economists, as it should be, and this is the reason why physicists should try to test any economic theory against data and treat it with skepticism before accepting it. Physicists should learn directly from the giants that both neoclassical and Marxists economic theories have ignored [1-8]. And it seems that they do since there is certainly an important amount of work on the new science: Econophysics (see figure 1).

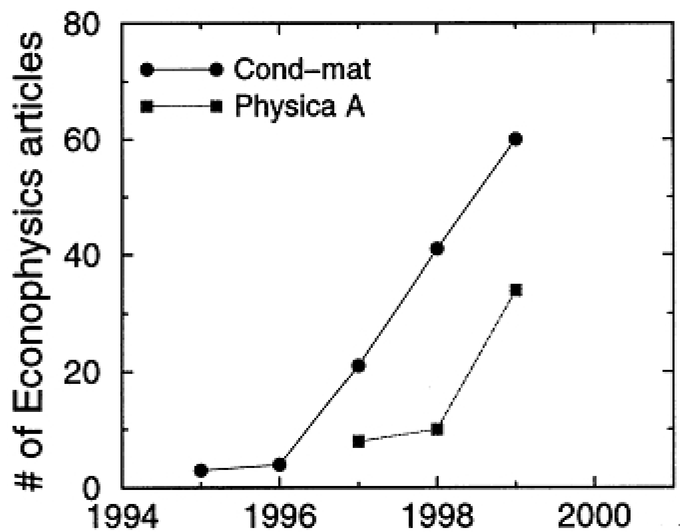

Fig. 1. The number of articles on econophysics that have appeared on the cond-mat preprint server and in the journal Physica A as of October 1999, obtained from the Los Alamos web server and the Science citation index respectively using the keywords stock, market, price, finance, financial, and options [9].

Financial markets can be regarded as complex systems [10]. In fact, they are systems consisted of many agents which are interacting between them in a highly nonlinear way. Financial markets are continuously monitored. Data exist down to the scale of each single communication of bid and ask of a financial asset (quotes) and at the level of each transaction (trade). The availability of this enormous amount of data allows a detailed statistical description of several aspects of the dynamics of asset price in a financial market. The results of these studies show the existence of several levels of complexity in the price dynamics of a financial asset [11-14].

Markets and economies in general are also teleological systems, but in a different way than non-human systems. The latter have only homeostasis and development of the systems while the former incorporate new aims, those of the human beings belonging to the system, and they are capable of incorporating the guessed consequences of their performance into the present decisions and definitions of new aims. They also learn from mistakes and from present developments, and they react, by changing both the actions undertaken and the aims defined; they are thus self-reflective. They also have the ability to adapt to new changing boundary conditions (a property also shown by non-human systems), but they may consciously alter the boundary conditions. This is why economy as a human system, can be understood as being complex, adaptive, self-reflective, and self-aware.

When analyzing their structure, economic systems are nested hierarchical systems. In the case of economic systems, we can distinguish several subsystems within them, and every part may be split into different industrial `types' (sharing common features) and so on. The various levels of an economic exchange human activity and exchange of energy between them, reflect the interconnected nature of those systems (the output of one sector enters other sector as input, and vice versa). That is, "downward and upward causation imply feedback between different levels of description in the hierarchy ... in mathematical terms it implies additional complexity and non-linearity such that an economic equilibrium is no longer evident and certainly cannot be easily calculated" [15].

Thus, the increased complexity of economies, their nested hierarchical nature, and the fact that they show adaptive and evolutionary behavior, gives rise to two parallel outcomes. One is the non-linear behavior (even chaotic behavior) that these systems show. This is a short run process that involves a given structure and the difficulty in comprehending it by using the traditional methods of analysis based on hard (quantitative) modeling. The other is the emergence of novelty, which is long run, and involves ***changes in the structures***. An alternative way of presenting this is by using the concepts of ***thermodynamics***.

From an academic point of view, financial time series represent an extremely rich and fascinating source of questions, where a trace of human activity is recorded and stored in a quantitative way, sometimes over hundreds of years. What are then the statistical features of a financial time series? Does it share common signatures with other signals that physicists have learned to cope with? Once we have a good model for price changes, what is it useful for? Do we understand the basic mechanisms, in terms of human psychology, market micro-structure, etc., that are responsible for the observed statistical peculiarities of price changes, and their universality across markets and epochs?

From a practical point of view, in the present work we try to study the Athens Stock Exchange, ASE, through its most important index GD and Lisbon's Market Main Index using simple methods of thermodynamics; in other words we try to see its change of structure, its evolution. The reasons that convinced us to do so is

- The important large scale movement of index in Greece during the period that this EU member was trying to be part of the European currency union. That's something that was clearly observed in Portugal too, an economy of the same magnitude, at the same economic period. As we will see, the indexes movement, were macroscopically the same.
- The fact that many people were involved in this economic motion, something that implies that the behavior was mostly kind of collective or even looking more like that of a herd. It was not a market for the experts or the specialists, that's why as we will see fundamental analysis or expertise were not the basic way of investing.

After all this, it is plausible to assume that a law governed this change of the indices, a law that shows the structure change. Our purpose is to study the empirical data and find that law and relate it to similar laws in physics.

2 Method

The data set that we use is simple day by day closing prices of the GD index of the ASE market for the last five years and day by day closing prices of Lisbon's main index for the last 10 years. As we will attempt to show this kind of behavior is mostly a result of the herding behavior that was introduced by Bouchaud and Potters [16] which indicates leptokurtic pdfs (probability density functions) and fat tail properties that were shown by Mills [17] at least for the ASE general index GD.

From a thermodynamic point of view [18-20], systems of economy behave in a manner shown in figure 2. A financial market is an open system since stocks can be bought and sold at a certain price. This is the analogy of an open thermodynamic system in which particles can get in and out of it with a certain amount of energy. In financial markets particles are the stocks and all the other exotic assets that we can trade in different kind of markets. The price of the stock also corresponds or better, is related to the chemical potential of the system. In thermodynamics, the chemical potential of a system is an expression of the system's state. This state in thermodynamics depends on the environment, which is described with macroscopic entities like temperature T or pressure P. When the system is placed in a hotter environment of bigger temperature, in other words, when it is in touch with a hotter reservoir, its temperature rises up according to the Newton's law and when it is placed in a lower temperature environment, i.e. in touch with a colder reservoir, then its own temperature declines following the same law. We are expecting to observe similar changes in the chemical potential which of course for the markets is corresponding to their prices. According to Newton's law, temperature T depends on time. This dependency is expressed with the following form

$$T-T_{res} = (T_o - T_{res})e^{-\lambda(t-to)} \qquad (1)$$

Thus in analogy we expect to observe a corresponding variation of price as a function of time as above.

Thermodynamics	Economics
Energy	Potential utility gains
Entropy	Variability of utility gains
Temperature	Size of potential utility gains
Pressure	Eagerness of individuals in exploiting utility gains
Force	Individuals looking for utility gains
Work	Realized utility gains
Heat	Inefficiencies in allocation

Table 1: Comparing the concepts of thermodynamics and economics.

Thermodynamics	$-F$	$-E$	TS	μ	N
Economics	W	U utility	Ψ surplus	P price	N of goods

Table 2. Summary of the suggested analogies between thermodynamic and economic systems.

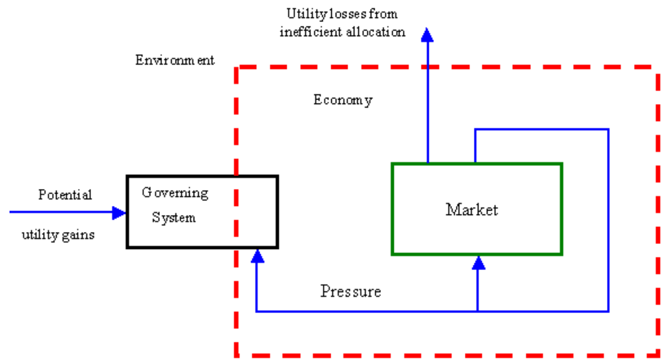

Fig. 2: Energy transformation in the economic system

3 Results and Discussion

Having all the above notes in mind, we can now display ASE GD and Portugal's Main Index in figures 3 and 4.

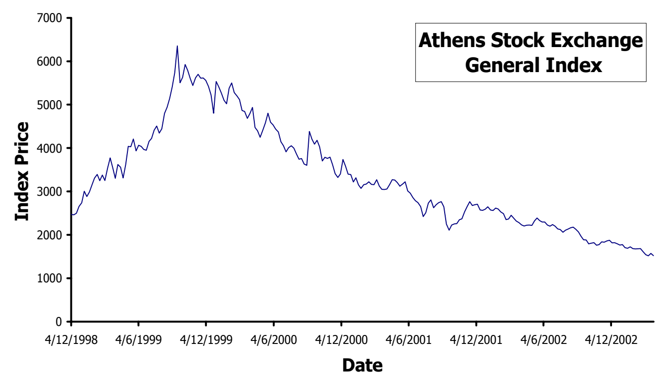

Fig. 3: Graph of ASE General Index for a 5 years period from 1998 to 2003. The graph is based on weekly closure prices of the index.

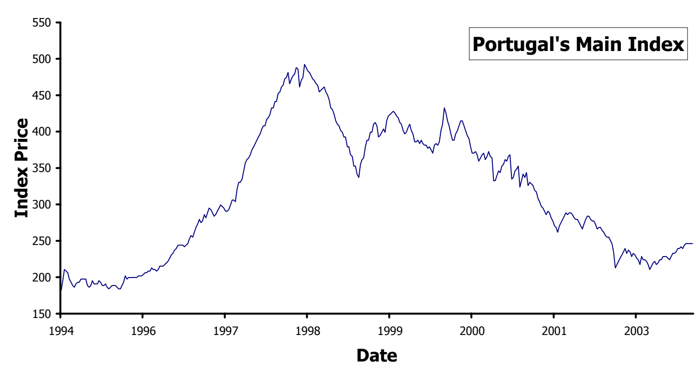

Figure 4: Graph of Lisbon's Main Index for a 10 years period from 1994 to 2003. The graph is based on weekly closure prices of the index.

As we can see, there is a main way of macroscopic behavior that is easy to observe in both diagrams. A huge "rally" of the prices in both cases was followed by a big turn downwards of the indices. In log scale, linearity in both cases is observed (figures 5-8), in both branches, before and after the turning point of the market.

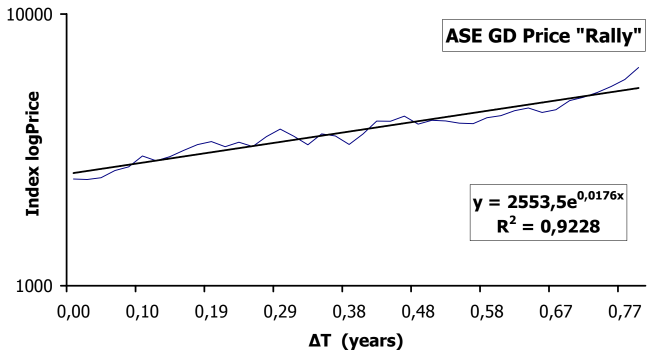

Figure 5: Exponential fit of the ASE General Index Prices and ΔT. The index prices are presented above in a log scale. ΔT is the date of market closure minus the date when the "rally" begun.

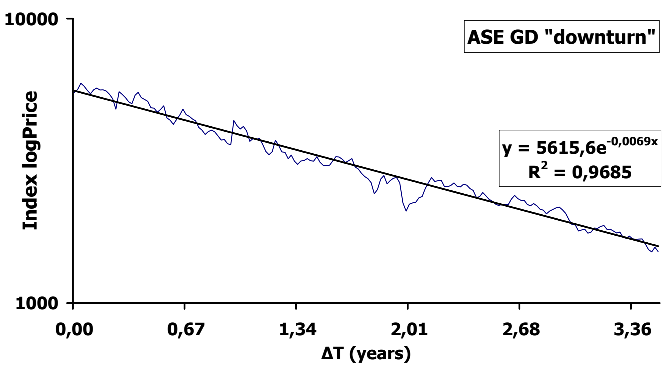

Figure 6: Exponential fit of the ASE General Index Prices and ΔT. The index prices are presented above in a log scale. ΔT is the date of market closure minus the date when the "downturn" begun.

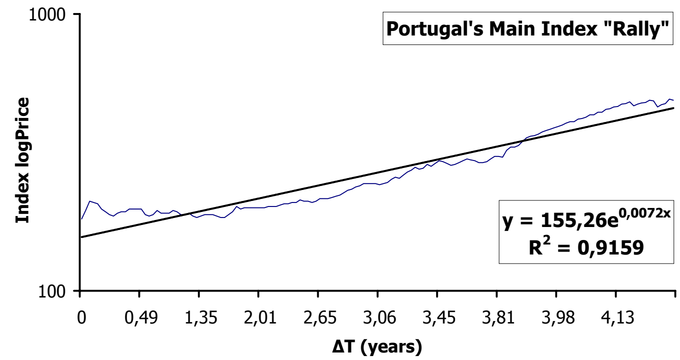

Figure 7: As figure 5 but for Lisbon's Main Index.

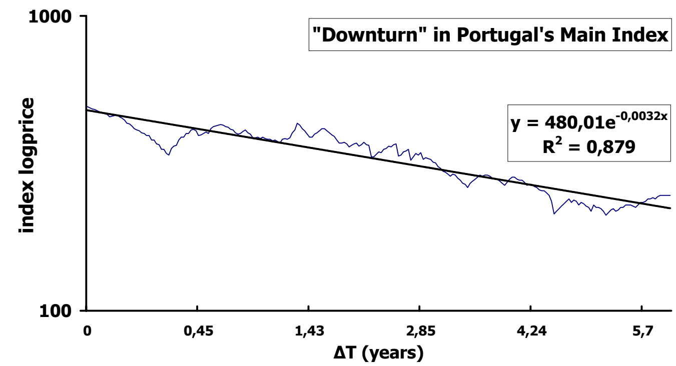

Figure 8: As figure 6 but for Lisbon's Main Index.

This seems quite enough to make us propose a law between the price of the indices and time of the form

$$P - P_{target} = (P_o - P_{target})\, e^{-\lambda t} \qquad (2)$$

This is of course similar to the Newton's law of cooling in physics. The Newton's law is the formula that describes the way a system is absorbing energy in a macroscopic way, using the magnitude of temperature. Suppose that the temperature of the system is T_o at time t_o. When tit gets in contact with an environment, which has higher temperature T_{res}, the heating process begins, and temperature rises up following an exponential law of the form Equation (1). At t_1 time units after the contact with a hotter reservoir, the system is at a new temperature T_1. If at that point in time, we bring the system in an environment, which has some lower temperature, a freezing process will begin which follows the same exponential law. That is why, at time t_2, the system will fall to a new temperature $T_2 < T_1$ since it is now heading to a state of thermal equilibrium with its environment of temperature T_o.

In correspondence with the above, we propose that, both in Greece and Portugal, the stock markets, as systems, were placed in an economic environment of temperature T_{res}, and experienced an exponential "heating process" until T_1. That followed in both cases by a "freezing process", which pushed the prices at a level close to that of the starting "economic environment temperature" T_o. In both cases, there is a slight difference between the starting environment temperature T_o and the final temperature T_{res}, something that under this point of view indicates the real amount of economic growth, in thermodynamic terms, in this time period.

The fact that there is a big difference between the real economic growth

$$\Delta T_{real}=T_2-T_0 \,, \qquad (4)$$

and the observed "expected" economic growth

$$\Delta T_{expected}= T_{res} -T_o \qquad (5)$$

in these stock markets, is a consequence of the herding behavior that took place in both cases from the micro investors that were the majority of the players both in absolute numbers and in capital terms. So, we can assume that "Newton's law kind of patterns" is the result of such collective responses of the investors. No rational fundamental analysis or chartist strategy can easily create such patterns in the stock markets.

Finally, by observing all the λ parameters that were calculated and that are shown at figures 5-8 and that are measures of the velocity of exponential increase or decay, we can easily calculate that in both markets, the speed of the heating process was two times bigger than the cooling process. More specifically, in Lisbon this factor is

$$\lambda_{heating}/\lambda_{cooling} = 0.0072/0.0032 = 2.25 \quad (6)$$

and in Athens it is

$$\lambda_{heating}/\lambda_{cooling} = 0.0176/0.0069 = 2.55 \quad (7)$$

This means that both stock markets general indices had the same variation between their growth and decline speed.

4 Conclusions

It has been argued in this paper that by using tools from thermodynamics and especially the Newton's cooling law we can image the macroscopic behavior of stock markets, like those of Athens and Lisbon that obey certain conditions:

- A huge amount of players participate in the buying and selling process and
- All these players present a herding behavior while investing.

References:

[1] Steve Keen, Standing on the toes of pygmies: Why econophysics must be careful of the economic foundations on which it builds, *Physica A* 324,2003 pp. 108 – 116.

[2] J.K. Galbraith, *The New Industrial State,* Houghton Mifflin, 1967.

[3] R.M. Goodwin, *Essays in Economic Dynamics*, Macmillan, 1982.

[4] J.M. Keynes, The general theory of employment, *Q. J. Econ.* 51, 1937, pp. 209–223.

[5] K. Marx, *Theories of Surplus Value*, Lawrence & Wishart, 1863.

[6] H. Minsky, *Inflation, Recession and Economic Policy*, ME Sharpe, 1982.

[7] J.A.Schumpeter, *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest and the Business Cycle,* Oxford University Press, 1934.

[8] T.Veblen, Why is economics not an evolutionary science? *Q. J. Econ*. 12, 1898, (Reprinted in (1919, The Place of Science in Modern Civilization, B.W. Heubsch, New York).

[9] J.-P.Bouchaud, K.Lauritsen, P.Alstrom, Proceedings of the International Conference on Application of Physics in Financial Analysis, *Int. J. Theor. Appl. Finance* 3 (3) 2000, pp. 309–608.

[10]Vasiliki Plerou, Parameswaran Gopikrishnan , Bernd Rosenow, Luis A.N. Amaral, H.Eugene Stanley Econophysics: financial time series from a statistical physics point of view *Physica A* 279, 2000, pp.443-456.

[11]P.W. Anderson, K.J. Arrow, D. Pines Editors, *The Economy as an Evolving Complex System, Addison-Wesley,* 1988.

[12]R.N. Mantegna (Ed.), Proceedings of the International Workshop on Econophysics and Statistical Finance, *Physica A* 269 (1), 1999, pp. 1–185.

[13]R.N. Mantegna, H.E. Stanley, *An Introduction to Econophysic s: Correlations and Complexity in Finance,* Cambridge University Press, 2000.

[14]J.-P. Bouchaud, M. Potters, *Theory of Financial Risk,* Cambridge University Press, 2000.

[15]Jeroen C.J.M. van den Bergh and John M.Gowdy, The microfoundations of macroeconomics: an evolutionary perspective, *Cambridge Journal of Economics* 27:, 2003, pp. 65-84

[16]Jean-Philippe Bouchaud An introduction to statistical finance. *Physica A* 313, 2002, pp.238 – 251.

[17]Terence C. Mills, Statistical analysis of high frequency data from the Athens stock exchange *Physica A* 293, 2001, pp. 566–572.
[18]Wayne M. Saslow, An economic analogy to thermodynamics *Am. J. Phys*. 67 (12), 1999, pp. 1239-1247.
[19]Raddai Raikhlin, *Civil War, Terrorism and Gangs*, Imprint Books, 2001.
[20] Eric Smith, Duncan K.Foley, Is Utility Theory so Different from Thermodynamics? *SFI 2002 Working Papers*.