Econophysics: a new tool to investigate financial markets

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The relationship between physics and economics has a long and interesting history. Outstanding economists of the past explicitly inspired their work to the principles of Newtonian physics and statistical mechanics, attracted by the success of these theories. However, despite the existence of many problems of common interest, the interaction between statistical physicists and economists has never been strong. The situation changed only recently, in the late nineties, when physicists and economists started talking to each other more and more frequently and a new interdisciplinary research field emerged: the term econophysics was created in order to outline the contribution of a new approach based on physical point of view in dealing with financial problems. The new field of econophysics applies the powerful methods of statistical physics and non linear dynamics to macroeconomic modeling and financial market analysis [1]. Financial markets represent a typical example of complex system where the price changes, apparently random, are the result of interactions among a high number of agents (the market operators) [2]. Therefore, financial markets can be studied using the same concepts developed in statistical physics for the study of complex systems. In addition, within economical and social sciences, a good and strict mathematical investigation can be performed in the analysis of financial markets.

In Italy there are several research groups which have dealt and are currently dealing with econophysics; they include researchers mainly from the field of statistical physics and of complex systems studies [3]. Following a recent transfer of competence from Italy to Australia, at the Australian National University (ANU) in Canberra there is the research group of T. Di Matteo, T. Aste and S. T. Hyde actively working on econophysics. The three scientists, together with E.S., are participating in the Italian Strategic Project: "High frequency dynamics of financial markets" funded by the Italian Ministry of Education, Research and Technology. Seven Italian research units are participating in this interdisciplinary project which started on July 2003 and it will last for three years.

There are various research activities and different approaches in the field of econophysics and this brief contribution is not designed to review all the works done in this rapidly developing area. Rather, this note offers an introduction that is sufficient to allow the reader to be aware of this new multidisciplinary field. Therefore, we here report only some of several interesting research subjects, in particular the research we are carrying on in our groups [1, 4, 5].

In the literature, many of the early works were dedicated to or inspired by the options pricing problem. In the early seventies, F. Black, M. S. Scholes and R. C. Merton made a major breakthrough in the pricing of stock options by developing what has become known as the Black-Scholes model [6]. These authors considered a portfolio of financial products (shares, obligations, currencies) and options defined on these underlying assets requiring this portfolio be risk less, that is independent from any stochastic variable. At the base of their formulation there was the hypothesis that stock prices are performing a geometric Brownian motion, with a constant drifting term. In 1997, the importance of the model was recognized when Scholes and Merton were awarded the Nobel prize for economics. Sadly, Fischer Black died in 1995, otherwise he also would undoubtedly have been one of the recipients of this prize. The hedge fund Long Term Capital Management, which included Scholes and Merton as partners, was founded with the principles of this model. We all know what happened next. In August and September 1998, the fund lost $4.5 billion, and had to be bailed out by its 14 biggest counterparties. The hypotheses of Black, Scholes and Merton's model (BS/M) hardly correspond with what is observed in real data. In particular, the volatility (standard deviation of price changes) and the risk-free interest rate are considered constant. However, in the financial practice, the hypothesis of time independence of these variables leads to economically relevant incorrect evaluations. In addition, the assumption that prices' returns were distributed in a normal way was challenged by the most recent analyses carried out on high frequency market data, showing the so called "fat tails" in the distributions of returns [1, 5, 7]. For some years now, according to the previous considerations, some authors have applied more or less significant variations to the BS/M model [4, 8, 9].

Besides the research on models for valuating pricing of a derivative product (when some of the assumptions of the BS/M model are relaxed) and methods for portfolio selection and its dynamical optimization [10] (area of major interest for financial institutions), another field in rapid development is the empirical study of price changes of a financial asset. Some studies focus on the shape of the distribution of price changes, others on the statistical properties of the higher-order moments of the distribution, others on the properties of the time correlation of a financial series and finally on phenomenological models for high frequency data [1, 4, 5, 11-16]. As previously noted, a financial market exhibits several features of the so called complex systems, that are open systems in which many subunits interact nonlinearly in the presence of feedback. The governing rules in financial markets are quite stable and the time evolution of the system is continuously monitored, so that large databases are accessible to the scientific community. This is why today we are able to develop statistical models and empirically verify their efficiency.

In this general framework, there are relevant results concerning the financial price changes described by a Lévy stable distribution, a stochastic process which obeys to a generalised formulation of the central limit theorem. A process in which the probability distribution has power law tail converges in the diffusive limit to a process with a Lévy stable distribution. The second moment of distribution (volatility) is infinite and several empirical works have been carried out in order to verify this hypothesis. Therefore, Lévy stable model has been corrected. One of the most interesting proposals is that of considering truncated Lévy processes, in order to describe the scaling relations of returns together with a finite volatility [1,9].

Another area of interest is the development of theoretical models to describe the global statistical properties of a financial market, which could represent an important instrument for example in the choice of a low risk portfolio or in the investigation of causes and effects of financial markets' crises. In this context, the study of correlations inside a financial market has a fundamental role [17-19]. The discovery of high-order correlations in price changes led to a reconsideration of many obvious aspects. Another relevant research area concerns the study of analogies and differences between price dynamics in a financial market and such physical processes as turbulence and biological and ecological systems [1, 4].

There are also studies that analyse the economic performances of complex organizations such as multinationals, universities and even nations. For example, we should mention studies of the income distribution of firms and of the statistical properties of their growth rates [20].
In conclusion, it should be noted that many subjects broached by researchers of econophysics have been debated for a long time also in other research fields, including financial mathematics, econometrics and quantitative finance. In our opinion, only following positive contacts between these disciplines we will reach a complete summary able to generate largely shared theories on complex systems and adequately describe the social and economical reality.

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Glossary
Derivative: an instrument whose price depends on, or is derived from, the price of another asset. Examples of derivative are futures and options.

Futures: a contract that obligates the holder to buy or sell an asset at a predetermined delivery price during a specified future time period. .

Options: there are two kinds of options: call and put. A "call" option gives the holder the right (but not the obligation) to buy an activity on a certain date (European option) or within a certain date (American option) for a price arranged at the moment of the agreement. A "put" option, instead, gives the right to sell an activity.

Returns: the percentage gain or loss for a mutual fund in a specific time period.

Volatility: The variation of movements in a security's price. Usually expressed by the standard deviation of the probability distribution of the logarithm of the security's price over one year.

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