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# Econophysics – A Tutorial Review

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***"Imagination is the highest form of research."*_**
*Albert Einstein*

**Abstract:** Physics is the oldest of the quantitative sciences, which occur because of the interaction between matter and energy in space with a specific time interval. Naturally it follows the laws of nature that cannot be controlled by humans. For the last three decades, physicists move beyond the boundaries of their discipline via various problems. This rapidly growing interdisciplinary field is now popularly called "Econophysics". It is an integration of economics and physics. In view of the above, this paper discusses a basic tutorial review concept on econophysics through different approaches to identify its broader scientific foundations in the social sciences and especially within economics.

**Keywords:** Economics; Econophysics; Physics; Quantum Mechanics; Social Science

## 1. Introduction

A phenomenon related to econophysics is its distinctiveness from the mainstream economics, although both sciences share the same subject of research. It seems quite strange, since physics has long been a source of inspiration for economists. Einstein once said that "thinking without the positing of categories and of concepts in general would be as impossible as is breathing in a vacuum". His remark echoes a long tradition of Western philosophy arguing that our experience and knowledge are structured by a framework of categories or general concepts.

Physics is a hardcore observational science; it does not accept theories or explanations unless they are verified and validated by experimental procedures as well. It is not always necessary that the developments in theoretical and experimental physics make simultaneous progress. After thirty years of its existence, econophysics significantly extended its scope of research and nowadays deals with practically the majority of contemporary economic issues.

## 2. What Econophysics is

Since its emergence, economics has been strongly methodologically linked to physics. Econophysics is most often understood as initiating progress in economics by using physics, Figure 1. The field of formal econophysics was developed a little more than three decades back. It is understood from the historical development of econophysics that the subject evolved due to the interest shown by physicist more than the economist. In the contemporary world, econophysics is an interdisciplinary study where economists study the theories of economics by applying the theories of physics as a tool.

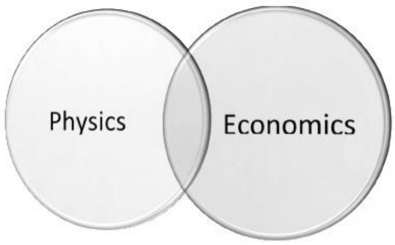


**Fig. 1:** Set Theoretic Concepts of Econophysics [3]

The classical era of econophysics was a period into many branches. For instance, during 1320-1382, Nicole Oresme worked in all topics including economics, mathematics, physics, astronomy, philosophy and theology. During 1642-1727, Isaac Newton was a noted physicist but contributed a good amount of time in economics. Similarly, during 1705-1757, James Dodson tried to apply mathematics and statistical methods in the field of insurance and finance and others experts.

Econophysics can be systematized in two ways. Starting with its definition, it indicates that the aim of this tutorial is an economic nature and physics provides the methodology, then resulting according to classical rules consistent with economics literatures in forms of textbooks. Therefore, econophysics is a science of a complex nature and can itself be the subject of complexity theory research.

*2.1 Definitions*

Bertrand Roehner (2005) defines it simply as: "**the investigation of economic problems by physicists**". Similarly, Mantegna and Stanley (2000) in a less general definition highlight that: "The word econophysics describes the present attempts of a number of physicists to model financial and economic systems using paradigms and tools borrowed from theoretical and statistical physics". The term "econophysics" is widely used (since 90s) to denote a new field of interdisciplinary research, where methodologies and tools from Physics, mainly Statistical Physics and dynamic systems, applied to solve several financial puzzles.

## 3.0 Development of Econophysics

The paradigm in Kuhnian understanding means the notional and theoretical bases of a given science. This understanding of Kuhn"s paradigm with a new notion replaces - the disciplinary matrix. This is a property common to all researchers representing a given science used as a platform for understanding. Modern general system theory is based on four components: cybernetics, catastrophe theory, deterministic chaos and sciences of complexity. This methodological foundation is used in multiple fields of sciences, therefore - with reference to the Kuhnian tradition. It seems that the transdisciplinary matrix has become a basis for permanent cooperation between representatives of both sciences, which is certainly favourable for the development of theory and practice of management. Economics, from its very beginning, was strongly related to physics, which provided it with the main source of inspiration and development. At the beginning of the 20th century, the developmental paths of economics and physics began to split, the consequence of which are the disproportions observed today.

*3.1 Postulates of Econophysics*

As economy as the science is the section of Natural sciences let us list the three known postulates as: (a) A postulate of continuum; (b) A postulate of duality; (c) A postulate of duality of a condition. The three postulates of Natural sciences have the following formulations: **(a) The postulate of continuum:** All structures of the Universe and the surrounding Reality arise, function and collapse in a continuum.**(b) The postulate of a duality:** Fundamental symmetry of Natural sciences is the duality.**(d) The postulate of a duality of a condition.** Conditions of objects of the Universe and the surrounding Reality contain regular and singular components.

## 4.0 Future Trends in Econophysics

Scholars from various fields are now trying to work on the field of econophysics. There are now specialized institutes or centers that are trying to promote interaction of natural science and social science. Many reputed Institutes and Universities are involved in research work of econophysics. However, the actual breakthrough in econophysics may take place only when certain fundamental issues are addressed properly.

Classical economics are basically built on strong assumptions which may not be always true for all conditions, as it deals with the behaviour of human beings. Phillip Protter is an expert on mathematical finance makes the following remarks: Mathematical finance... is a difficult subject, requiring a broad array of knowledge of subjects that are traditionally considered hard to learn. One sometime hears that “compound interest is the eighth wonder of the world”, or the “stock market is just a big casino”. The time value of money and uncertainty are the central elements influencing the value of financial instruments. The study of the more sophisticated financial instruments called derivatives.

The behaviours and the nature of decisions made by humans are not always static and have ample chances to vary from person to person. These unpredictable events make the study of economics related with the human nature more difficult in applying the physical laws that are established without any emotional attachments. The time evolution of asset price in economics may be related to non linear deterministic dynamics in the near future with the help of biological and physical systems. The chaos theories in physics have to be utilized to answer the long pending questions in economics. The concept of scaling, universality disordered frustrated systems and self organized systems will help in the modelling of economic systems.

### *4.1 Forecasting of Econophysics*

Forecasting in a broad sense is the central problem of econophysics. For example, the basic problem in an estimation of risky financial assets is the prediction of the future on the basis of the present (current) information. Forecasting is one of the basic tools, methods, elements of economic planning and modelling. In the certain sense, studying of the dynamics of financial economic objects, systems, structures and entities in chaotic diffusion environment is devoted to the purpose of forecasting. In this connection we shall note, that one of the key problems of econophysics is stochastic dynamics of stock exchange.

*4.2 Statistical Mechanics in Econophysics*

Statistical mechanics is defined as: “branch of physics that combines the principles and procedures of statistics with the laws of both classical and quantum mechanics, particularly with respect to the field of thermodynamics. It aims to predict and explain the measurable properties of macroscopic (bulk) systems on the basis of the properties and behaviour of their microscopic constituents.” Britannica (2009)

The tools of statistical mechanics or statistical physics Reif (1985); Pathria (1996); Landau (1965) that include extracting the average properties of a macroscopic system from the microscopic dynamics of the systems to prove useful for an economic system, because even though it is difficult or almost impossible to write down the “microscopic equations of motion” for an economic system with all the interacting entities, in general, economic systems at various size scales, Figure 2.

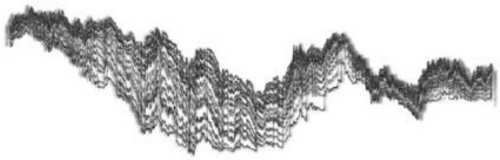

**Fig. 2:** Statistical Nature of Financial System [5]

The understanding of the global behaviour of economic systems seems needs such concepts as stochastic dynamics, correlation effects, self-organization, self-similarity and scaling, and for their applications.

## 5.0 Kinetic Exchange Models: Modelling in Econophysics

Physicists contribute to the modelling of „complex systems‟ by using tools and methodologies developed in statistical mechanics and theoretical physics. As financial markets remarkably well-defined complex systems, so they are continuously monitored - down to time scales of seconds. Economists and mathematicians are the researchers with the longer tradition in the investigation of financial systems. Physicists, on the other hand, have generally investigated economic systems and problems only occasionally. Recently, however, a growing number of physicists is becoming involved in the analysis of economic systems. Since the 1970s, a series of significant changes has taken place in the world of finance. Black and Scholes published the first paper that presented a rational option-pricing formula.

The Swiss physicist and mathematician, Daniel Bernoulli, who published *Hydrodynamica* in 1738, that led to the formulation of the "kinetic theory of gases". He proposed for the first time: (i) gases consist of a large number of molecules moving in all directions, (ii) their impact on a surface causes the gas pressure, and (iii) heat is simply the "kinetic energy of their motion". Then in 1859 the Scottish physicist, James Clerk Maxwell, formulated the "Maxwell distribution of molecular velocities", based on the diffusion of molecules by Rudolf Clausius. This considered as the first *statistical law* in physics." The subject of statistical mechanics provides a theoretical framework for relating the microscopic properties of individual atoms and molecules to the macroscopic or "bulk" properties of materials. It can be applied to various systems with an inherently *stochastic* nature in the fields of physics, chemistry, biology, and even economics and sociology. In fact, the application of statistical physics ideas and tools in modelling economics have led to the interdisciplinary fields of "Econophysics".

A natural question may rise in one"s mind is: "*How can such a physical theory like statistical mechanics, which deals with particles, be applied to an economic system, composed of (human) agents?*" Physicists have come up with simple kinetic exchange models in recent times to the economic problem, based on the simple philosophy: A single molecule of gas does not have a temperature ($T$), or a pressure ($p$). It is simply a point-like particle that moves at a particular speed, depending on how much energy it has, governed by the statistical law of Maxwell-Boltzmann distribution of molecular speeds. The alternate approach proposed by physicists is that the agents can be simply viewed as gaseous particles exchanging "money", in the place of energy, and trades as money (energy) conserving two-body scatterings, as in the *entropy maximization* based kinetic theory of gases. This qualitative analogy between the two maximization principles seems to be quite old – both economists and natural scientists, but this equivalence has gained firmer ground only recently. In Europe Vilfredo Pareto found that wealth distribution follows a power law tail for the richer section of the society, known now as the *Pareto law*.

The distribution of income $P(x)$ is defined as follows: $P(x)dx$ is the probability that in the "equilibrium" or "steady state" of the system, a randomly chosen person would be found to have income between $x$ and $x + dx$. Detailed empirical analyses of the income distribution so far indicate:

$$P(x) \sim x^{n} \exp(-x/T)\ , \quad x < x_c \qquad (1)$$

$$P(x) \sim x^{-a-1}, \qquad x < x_c \qquad (2)$$

where $n$ and $a$ are two exponents, and $T$ denotes a scaling factor. The latter exponent a is called the *Pareto exponent* and its value ranges between 1 and 3. The crossover point $x$ is extracted from the numerical fittings of the initial Gamma distribution form to the eventual power law tail. Figure 3 shows chematically the features of the cumulative income or wealth

distribution pattern.

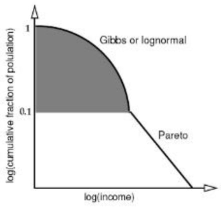


**Fig. 3:** Gibbs Distribution:

The cumulative wealth (income) distribution vs. the wealth (income)[11]

## 6.0 Conclusion

Econophysics is a new word, used to describe work being done by physicists in which financial and economic systems are treated as complex systems. This tutorial is of a bidirectional nature. There have been issues raised by certain economist about the inability of the law of physics to solve the problems of economics. We should not be confined to the past schools of thoughts where interdisciplinary approach was very rare. Rather, we should consider this as a challenge where the problems in economics are not only solved by the use of the laws of physics but more general theories are developed in physics by traversing beyond the boundary of conventional physical laws.

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