From Edgeworth to Econophysics: A Methodological Perspective

Drakopoulos, Stavros A. and Katselidis, Ioannis

University of Athens

May 2013

From Edgeworth to Econophysics: A Methodological Perspective

By

Stavros A. Drakopoulos and Ioannis Katselidis
(University of Athens)
(Athens University of Economics and Business)

May 2013

Abstract

Although most of the marginalist economists' methodology was influenced by 19th century classical physics, the work of second generation marginalist Francis Ysidro Edgeworth represents the highest point of classical physics influence to the development of mainstream economic methodology. Edgeworth's close parallelism between celestial and social mechanics expressed in his analogies between utility and energy and the principle of utility maximization to maximum energy, are important indications of the physics scientific ideal for economics. Subsequent leading theorists were not as explicit, although economic theory continued to be influenced by physics scientific ideal as the work of Pareto, Fisher and Samuelson indicates. However, the physics methodological framework has made a recent reappearance in the relatively new field of econophysics. Although there are methodological similarities, there are also important differences between mainstream economics and econophysics. Econophysicists' emphasis to statistical mechanics rather to mechanical models, their reservations towards rational agent theory and their rejection of many standard assumptions of mainstream economics, are examples of such differences. This might also explain the resistance of mainstream economic theorists to incorporate econophysics into economics. The paper examines the above from a methodological viewpoint. It also discusses the possible reasons for this historical development and its implications for economic methodology.

Keywords: Economic Method, Econophysics, Edgeworth
JEL codes: B4, B00, A12

I. Introduction

The physics methodological ideal has been extremely influential for the formation of mainstream economic methodology (Mirowski, 1989). Although, there were indications of this ideal in classical economic thought (e.g. Adam Smith's reference to astronomy), the decisive turn took place with the emergence of marginalism. The introduction of marginal analysis was combined with the systematic use of mathematics by Jevons and Walras in their effort to make economics an exact science in the manner of physics (Mirowski, 1989; Dow, 2002). However, the work of second generation marginalist, Francis Ysidro Edgeworth represents the highest point of classical physics influence to the development of mainstream economic methodology. Although his contribution in this respect has not been widely appreciated, Edgeworth not only applied formalism and methods from physics to the study of economic phenomena, but he also provided the methodological justification. Edgeworth's approach dominated the bulk of orthodox economic methodology as the subsequent works of Pareto, Fisher and more recently Samuelson, demonstrate. The mathematical methods employed in their work, were very similar to the ones used in mathematical physics and especially to those of classical mechanics (Drakopoulos, 1994).

The more recent history of mainstream economic methodology indicates that the physics ideal was toned down although the methods were basically unchanged. However, the physics scientific ideal has made a recent reappearance in the relatively new field of econophysics. Contrary to previous developments, most of econophysicists' work originates from physics (Gingras and Schinckus, 2012). Although most of econophysicists acknowledge their intellectual debt to the above figures, there are important methodological differences between mainstream economics and econophysics (e.g. Burda et al, 2003; Ball, 2006). Econophysicists' emphasis to statistical mechanics rather to mechanical models, their serious reservations towards microeconomic foundations and their explicit rejection of rational agent theory as well as of standard concepts such as utility, are clear examples of such differences. Thus, it seems that contrary to the physicalism of marginalists, the physics ideal proposed by econophysicists does not combine very well with the established theory and method of orthodox economics. In addition, most econophysicists are highly critical of economic methodology to the extent that some of them call for its complete rejection (e.g. McCauley, 2004). The dominant orthodox reaction is to ignore the challenge, and when they respond, their reaction is rather subdued, implying a certain methodological discomfort.

The paper traces the development of physics scientific ideal in economics starting from the vital contribution of Edgeworth and proceeding to Pareto, Fisher and Samuelson. The next section discusses the emergence of econophysics and its main methodological approach in studying economic phenomena. Section four examines the differences of econophysics from orthodox economics and also their uneasy relationship. The next section focuses on the possible implications for mainstream economic methodology and the final section concludes.

II. Edgeworth's Methodological Ideal

A contemporary of Marshall, Edgeworth is considered to be one of the most influential figures of marginalism and of the early neoclassical economics. Apart from his well-known contributions to contract theory, the theory of monopoly and duopoly and taxation theory, his methodological approach was extremely influential for the subsequent development of mainstream economic methodology. Edgeworth's most important contribution "*Mathematical Psychics: An Essay of the Application of Mathematics to Moral Sciences*" (1881) sets the basis for the methodological justification of formalism in social sciences and particularly in economics. The subsequent influence of this work has not been fully appreciated by economic methodologists. Although there were previous methodological justifications for the use of formalism in economics (e.g. Cournot, Jevons, Walras), Edgeworth provides a very systematic methodological grounding for the use of mathematics in the study of social phenomena and more importantly of the methodological ideal of physics. It can be argued that his work represents the height of the physics emulation in the history of economic thought.

In the very first page of the introduction of the *Mathematical Psychics*, he sets his basic idea of the close analogy between economics and physics:

> An Analogy is suggested between the Principles of Greatest Happiness, Utilitarian or Egoistic, which constitute the first Principles of Ethics and Economics, and those Principles of Maximum Energy which are among the highest generalizations of Physics and in virtue of which mathematical reasoning is applicable to physical phenomena quite as complex as human life (Edgeworth, 1881, p. v).

In the process of his methodological justification, Edgeworth discusses the nature of the relations in economics with those in physics. He argues that the lack of precise numerical data and exact functional relations in economics is not an obstacle to the application of mathematical methods. In particular, he provides an example from hydrodynamics where the relations among variables are central (Edgeworth, 1881, pp. 4, 5). Edgeworth's purpose was to employ the methods of mathematical physics to social science. He continues by stating:

> The application of mathematics to the world of soul is countenanced by the hypothesis (agreeable to the general hypothesis that every psychical phenomenon is the concomitant, and in some sense the other side of a physical phenomenon), the particular hypothesis adopted in these pages, that Pleasure is the concomitant of Energy. *Energy* may be regarded as the central idea of Mathematical Physics; *maximum energy* the object of principal investigations in that science. By aid of this conception we reduce into scientific order physical phenomena, the complexity of which may be compared with the complexity which appears so formidable in Social Science (Edgeworth, 1881, p. 9).

Thus, the correspondence between physical and social phenomena is an important methodological reason for the physics scientific ideal. Furthermore, Edgeworth provides another fundamental reason for the application of mathematics to economics which is the quantitative nature of the discipline. Quantity of labour, quantity of pleasure, quantity of sacrifice and enjoyment, greatest average happiness are cited as main examples of the quantitative nature of economics (Edgeworth, 1881, pp. 97, 98).

Edgeworth combined Utilitarianism with economics under the methodology of “mathematical psychics” (see also Creedy, 1980; Mirowski, 1994). Therefore, the central idea of the “Hedonic Calculus” is the maximization of utility which naturally facilitates the application of optimization methods from physics to economics. The following statement is indicative:

> Now, it is remarkable that the principal inquires in Social Science may be viewed as *maximum-problems*. For Economics investigates the arrangements between agents each tending to his own *maximum* utility; and Politics and (Utilitarian) Ethics investigate the arrangements which conclude to the *maximum* sum total of utility. Since, then, Social Science, as compared with the Calculus of Variations, starts from similar data -*loose quantitative relations*-and travels to a similar conclusion –determination of *maximum*- why should it not pursue the same method, Mathematics? (Edgeworth, 1881, pp. 6, 7)

Given the above statements, psychophysics represents the aim of a unified science of physical and mental phenomena. Thus, he often cites with enthusiastic approval contemporary works in psychology and especially the work of psychophysicists such as Weber, Fechner, and Wundt (Edgeworth, 1881, p. 60).[1] Furthermore, he was extremely keen in incorporating the findings of psychophysics into the economic and utilitarian calculus (see also Collander, 2007). A good example in this respect, is Fechner's Law which relates the quantity of sensation to the quantity of stimulus (intensity of stimulus), and the stimulus threshold. In his previous work (Edgeworth, 1877), he modified this "Law" in view of his subsequent hedonic calculus as follows:

$$\pi = k|f\left(y\right) - f\left(\beta\right)$$

π is a pleasure function and it is an increasing concave function of the stimulus, y is the quantity of stimulus, β denotes the sensibility to the stimulus of the sentient, i.e. the threshold, and *k* denotes the capacity for pleasure. The first differential of this function is positive and the second is negative (Edgeworth, 1877, p. 42). He will employ this relationship in order to set a basis for his utilitarian calculus where he ultimately links it to the Bentham's Greatest Happiness Principle and even to the Malthusian relationship between the quantity of food and the number of population (see also Newman, 1987, pp. 90-91). Moreover, Edgeworth contributed greatly to the spread of statistical methods in economics. His works "*Methods of Statistics*" (1885) and "*Observation and Statistics*" (1887) became extremely influential for the theory and application of statistical techniques to social and economic data (see also Stigler, 1986; Baccini, 2007).

In general, Edgeworth's methodological approach is the peak of the combination of the application of mathematical physics to economics. His

---

[1] One can note here the contrast with the subsequent aversion by most orthodox theorists of incorporating research from psychology into economics (see also Lewin, 1996).

identification of maximum energy of physics with that of the maximum pleasure in economic calculus is his starting and also his central point. Moreover, his conception of man as a pleasure machine implies the legitimacy of incorporating psychophysics into economic theory. Therefore, his work represents the epitome of the attempt to transform economics into exact science in the manner of physics, through the adoption of the methodological tools of mathematical physics.

III. Subsequent Developments

After Edgeworth's methodological justification of the physical science scientific ideal, there was further incorporation of mathematical methods in economic theory. As will be seen, this approach dominated fairly quickly the bulk of mainstream economic theorizing. The economic thinking expressed in the works of Pareto, Fisher, and more recently, Samuelson, contributed and facilitated the incorporation of this methodological ideal.

Vilfredo Pareto's well-known methodological position regarding positivism and social sciences, were influential for the formation of mainstream economic methodology (McLure, 2001). Pareto's ideas were heavily based on the prevailing positivist scientific philosophy, a basic characteristic of which was the exclusion of all "metaphysical" and "non-scientific" elements from economics. Pareto's methodological ideal of economics was that it should be a mathematical science, part of the natural sciences such as physiology, chemistry and mechanics (Pareto, 1896, p. 21). This implies that economics should be freed from any philosophical or psychological ideas which hamper the application of the positivist methodology (for an extensive discussion, see Seligman, 1969; Drakopoulos, 1997; Dow, 2002). The following quotation from Pareto captures the link between formalization, expulsion of metaphysical elements and the physics ideal:

> Thanks to the use of mathematics … the theory of economic science thus acquires the rigor of rational mechanics; it deduces its results from experience without bringing in any metaphysical entity (Pareto, 1971, p. 113).

In the same manner as Edgeworth, the lack of formalism and the verbal mode of analysis that characterized social sciences were seen as a serious obstacle to the further progress towards the scientific status of the natural sciences. As he writes:

> All the natural sciences now have reached the point where the facts are studied directly. Political economy also has reached it, in large part at least. It is only in the other social sciences that people still persist in reasoning about words; but we must get rid of that method if we want these sciences to progress (Pareto, 1971, p. 10).

Thus, the concept of scientific progression for the social sciences was clearly identified with the adoption of mathematical formalism, an idea which also dominates contemporary mainstream economic theorizing.[2]

One indicative example of Pareto's belief in the analogy of physics and economics is the well-known Pareto's Law referring to the distribution of income. Although Pareto denied that this relationship had the status of a physical law, he was convinced of its universal nature given that it involved statistical values that can be estimated (Pareto, 1897). As we shall see, Pareto's law is one of the relations that econophysicists describe as power laws and falls into their domain.

---

[2] It should also be noted that in spite of the above, Pareto was careful regarding the application of the above to a model of economic man. In particular, Pareto admits that man's character presents other characteristics too, but these are studied by other sciences. Pareto envisaged a general synthesis of all aspects of human action which would be the subject of the science of Sociology (see also Bruni and Guala, 2001; McLure, 2010).

The next figure who contributed to the formation of current ideas about method in economics was Irving Fisher who is considered to be one of the most important promoters of marginalism in America. In line with Edgeworth and Pareto, his methodological viewpoint is focused on the analogy between economics and physics. Given that one of Fisher's doctoral supervisors was the theoretical physicist Willard Gibbs, it is not surprising that in order to complement the arguments in his doctoral thesis, he built an elaborate hydraulic machine with pumps and levers, allowing him to demonstrate visually how the equilibrium prices in the market adjusted in response to changes in supply or demand (Tobin, 1987). The following quotation provides the core of Fisher's methodological viewpoint:

> The introduction of mathematical method marks a stage of growth –perhaps it is not too extravagant to say, the entrance of political economy on a scientific era (Fisher, 1892, p. 85).

Apart from the above general methodological stance, Fisher promoted the specific mathematical methodology of optimization under constraints, that was to become standard in economic modeling. As J. Tobin states: "On a remarkable range of topics, modern theorists adopt and build upon Fisherian ideas, sometimes unknowingly. Fisher's methodologies, not just his use of mathematics but his explicit formulations of problems as constrained optimizations, is the accepted style of present-day theorizing" (Tobin, 1985, p. 34). This particular method was widely applied to problems in classical physics and especially classical mechanics.

Furthermore, a substantial number of pages in Fisher's most important work are devoted to the demonstration of the analogies between economics and physics. Fisher was convinced that terms from physics correspond to terms in economics, thus supporting explicitly the analogy between economics and classical mechanics. He presents a list of terms that economists use and which have been employed from physics. Examples are: equilibrium, stability, elasticity, expansion, inflation, reaction, distribution (price), levels, movement, friction (Fisher, 1892, p. 24). He proceeds by constructing a table of correspondence between classical mechanics and economics. In this table, a particle in physics corresponds to an individual in economics. Likewise, force and work correspond to utility and disutility respectively. Other interesting examples are: the net energy of a particle may be defined as the total energy less total work and by analogy, the net utility or gain of the individual is the total utility less total disutility (Fisher, 1892, p. 85).

The next important step of the development of the physics ideal in economics is to be found in Paul Samuelson's work and especially in his extremely influential *Foundations of Economic Analysis* (1947). One of the principal aims of this work was to build a formal theory of choice without resorting to "subjective" concepts such as utility or satisfaction (see also Wong, 1978). In a subsequent article reflecting on the formation of his ideas and especially of his *Foundations*, Samuelson emphasizes his influence and inspiration from the methodology of physics. As he writes:

> Perhaps most relevant of all for the genesis of Foundations, Edwin Bidwell Wilson (1879–1964) was at Harvard. Wilson was the great Willard Gibbs's last (and, essentially only) protege at Yale. He was a mathematician, a mathematical physicist, a mathematical statistician, a mathematical economist, a polymath who had done first-class work in many fields of the natural and social sciences. I was perhaps his only disciple . . . I was vaccinated early to understand that economics and physics could share the same formal mathematical theorems (Euler's theorem on homogeneous functions, Weierstrass's theorems on constrained maxima, Jacobi determinant identities underlying Le Chatelier reactions, etc.), while still not resting on the same empirical foundations and certainties (Samuelson, 1998, p. 1376).

It is interesting to note though, that in the last phrase of the last sentence, Samuelson admits an important difference between economics and physics: the lack of solid empirical foundations of economics. This is in contrast to Edgeworth's and Fisher's certainty of a close analogy between the two disciplines.

The modern subfield of financial economics is a representative example of an example of Samuelson's influence. The mathematical techniques used nowadays in the study and the future behaviour of exchange-traded options markets, derivatives and other structured financial products, are based to a large extent on mathematical methods popularized by Samuelson (see also Lo and Mueller, 2010).

Thus, one can easily discern a common methodological position of the above three influential economists. In the spirit of Edgeworth, they strongly adhered to the physics analogy as the scientific ideal for economics. Moreover, the mathematical methods employed, were very similar to the ones used in mathematical physics and especially to those of classical mechanics. The basic common idea was the foundation of an economic agent characterized by utility maximization. This behavior can be approached mathematically and serve as a microeconomic basis for analyzing macroeconomic phenomena. Modern orthodox economic theory is therefore based on rational agent and employs most of the standard mathematical tools that Edgeworth and others introduced.

III. Econophysics: Emergence and Main Features

As was discussed in the previous section, at least since the era of the marginalist revolution, there has been a long-established connection between physics and economics. The physical science constituted a methodological ideal for economics, thus economists should adopt-imitate the methodological approaches of physicists. The study of economic phenomena with the aid of models and methods of physics has experienced a surge of interest through the emergence of “econophysics” in the 1990’s, which may be regarded as a new episode in the development of the above-mentioned relationship.

The term “econophysics” has been coined in 1996 by the physicist Eugene H. Stanley and, obviously, this neologism originates from the contraction of “economics” and “physics” and “denotes the activities of physicists who are working on economics problems to test a variety of new conceptual approaches deriving from the physical sciences” (Mantegna and Stanley, 2000, pp. viii-ix). This new research field, mainly consisting of academic physicists, has grown rapidly in the last decade or so (see also the review by Gingras and Schinckus, 2012). It uses theories and methods of physics, specifically statistical physics, in order to describe and analyze economic and financial phenomena, such as the stock market functioning or the distribution of income.

In most reviews of econophysics published mostly in mainly physics journals, econophysicists acknowledge the methodological link of their approach to early economics authors. For instance, they cite Adam Smith’s reference to astronomy as a possible model for scientific inquiry (Burda et al, 2003). They also point out the contributions to this aim of marginalists such as Jevons, Walras, Edgeworth, Fisher and Pareto emphasizing though, that their approach to modeling the economy was from classical mechanics and had the notion of equilibrium as a central concept (Burda et al, 2003, p. 2; Carbone et al, 2007).

There were various factors which contributed to the emergence and development of econophysics. The evolution of computer science facilitated the introduction of electronic transactions system in the 1980’s, making the collection and storage of huge amount of data easier. Physicists, accustomed to searching for universal laws, considered that these economic data could be analyzed with the tools of statistical mechanics and statistical physics, attempting to find empirical regularities which are present and perceived in all markets. In addition, new mathematical tools and modern probability theory have encouraged research into the distribution of stock market variations, and generally financial behaviour. Financial data seems to follow a non- normal distribution due to the presence of fat tails which are better explained by power law distributions, first studied by Vilfredo Pareto in 1897 with respect to income distribution. Non-Gaussian distributions and scaling laws are common in problems of physics like e.g. phase transition (see also Rickles, 2007).

Econophysicists regard "economic systems as complex systems whose internal microscopic interactions can generate macroscopic properties" (Schinckus, 2010c, p. 3815). Modern financial markets can be characterized as complex systems, since they are "open" systems in which many sub-systems interact non-linearly in the presence of feedback. However, open systems are also influenced by external factors. For instance, the global financial market seems to behave like a complex system, in which the domestic financial markets are complex subunits interacting with the various business sectors or even individual firms.

The fact that all economic agents and their actions are interdependent in the modern economic world and these interactions have a non-linear nature, gave rise to an attempt towards analyzing the afore-mentioned statement with the aid of the mathematics of chaos, a well-known tool among physicists. "The chaos theory has shown that unpredictable time series can arise from deterministic nonlinear economic systems and theoretical and empirical studies have investigated whether the time evolution of asset prices in financial markets might indeed be due to underlying nonlinear deterministic dynamics of a relative limited number of variables" (Săvoiu and Iorga–Simăn, 2008, p. 31).

Although the bulk of econophysics work is focused on the financial economics, there are also many studies focusing on macroeconomic phenomena. It is interesting to note the lack of any reference to macroeconomic theory, thus implying the a-theoretical nature of this approach. The macroeconomic system is usually conceived as a large complex system similar to physical systems:

> An alternative approach is the search for universal laws which govern the behavior of the complex system. Such laws may uncover global regularities which are insensitive to tiny changes of parameters within a given class of parameters. Such laws also provide a classification of possible universal large scale behaviors which can occur in the system and which can be used as a first order approximation in the course of gaining insight into the mechanisms driving the system. This approach has been successfully used in theoretical physics for a long time … Macro-economical systems are in this respect very similar to field theoretical ones (Burda et al, 2003, p. 5).

For most econophysicists, the conception of the macroeconomic phenomena in the above terms implies that the concept of a representative agent employed in most macroeconomic models is obsolete and useless. The appropriate methodology for examining these complex systems is the method of statistical physics or statistical mechanics. The widely used procedure involves the extraction of average properties of a macroscopic system from the microscopic dynamics of the systems (see Chakraborti et al, 2011a,b).

The issue of wealth and income distribution is also another area where many econophysicists believe that economic theory is seriously lacking and that they can offer new insights. For most studies, the starting point is Pareto's theory of distribution which may be written as:

$N(x) = Ax^{-\alpha}$

where N(x) is the number of people having an income greater than or equal to x, and α is the Pareto coefficient which is measured empirically. After discussing the lack of progress in empirical analysis done by economists, they advocate the use of methods from physics (e.g. Burda et al, 2003). Most econophysicists view this as a power law problem which can be analyzed starting from the "microscopic equation" that governs the dynamics of the evolution of wealth distributions which would lead to predicting the observed shape of wealth distributions (Chakraborti et al, 2011b; Lux, 2005). The following passage is indicative of the methodology employed:

> To explain such empirical findings, physicists have come up with some very elegant and intriguing kinetic exchange models in recent times ... Though the economic activities of the agents are driven by various considerations like "utility maximization", the eventual exchanges of money in any trade can be simply viewed as money/wealth conserving two body scatterings, as in the entropy maximization based kinetic theory of gases (Chakraborti et al, 2011a, p. 992).

The subsequent analysis is often conducted in terms of a close analogy between the kinetic theory of gasses and the kinetic theory of wealth. This means that there is a direct correspondence of concepts. As the following table indicates:

	Kinetic Model	**Economy Model**
variable	K (kinetic energy)	x (wealth)
units	N particles	N agents
interaction	collisions	trades
dimension	integer D	real number D
equilibrium distribution	the same	the same

(Chakraborti et al, 2011b, p.1027)

It is quite revealing that the above table resembles the table of correspondence between economics and physics terms and concepts found in Fisher's work. It is also in the same spirit as Edgeworth's close analogies between economics and physics concepts.

The study of economic crises and cycles is also an increasingly popular topic for econophysicists especially since 2008. Their starting point is that the usual Gaussian framework adopted by many economists does not predict outliers; hence extreme phenomena are not likely to happen, a result that is also confirmed by the stability feature of the above-mentioned framework. Moreover, economic reality and in particular economic crisis, should not be explained through an atomistic reductionism, namely through (alleged) principles which govern the individuals' behaviour. For econophysics, the microeconomic foundation of individual rationality is unnecessary and thus, no assumptions are made referring to agents' behaviour:

> Economic and financial systems consist then of a large numbers of components whose interactions generate observable emergent properties (scaling laws) totally independent of microscopic details (individual behaviour) (Schinckus, 2010c, p. 3818).

The alternative for econophysicists is to approach the problem of economic and financial crisis purely in terms of a physical phenomenon and more specifically, as interactions between the various parts of the system such as firms, banks and households (e.g. Stanley et al, 2007). This means that "from this perspective, the analysis of a crisis phenomenon (and its repercussions on investment or consumption) becomes possible" (Schinckus, 2010c, p. 3818). As an indicative example, in order to tackle the evolution of the economic system, one influential paper employs "death and birth reactive lattice gas process" along a microscopic physics like approach in order to describe a specific evolution of macroeconomic variables. This gas model takes into account the influence of an economic environment on the fitness and concentration evolution of economic entities (Ausloos et al, 2004).

IV. Econophysics and Orthodox Economic Theory

Most econophysicists realize some similarities with orthodox economics. As was pointed out above, they refer to the early attempts by economists to follow and adopt the methods from classical physics. However, they are also highly critical of contemporary economic theory and method. One of the most important criticisms is directed towards the use of tools from classical mechanics (e.g. constrained maximization) and of the Gaussian framework for empirical analysis. Standard economics often assume Gaussian normal distribution or some transformation of it. The Gaussian theory dates back to Bachelier, a French mathematician, who, five years before Einstein, in 1900, formulated the theory of Brownian motion in order to model the pricing of options in financial markets (Mantegna and Stanley, 2000). The mean-variance approach to risk analysis constituted the development of the above-mentioned theoretical framework, leading also to the formation of the famous Black-Scholes formula of option-pricing (Black and Scholes, 1973). However, "the usual measure of risk through a Gaussian volatility is not always adapted to the real world. The tails of the distributions, where the large events lie, are very badly described by a Gaussian Law: this leads to a systematic underestimation of the extreme risks. Sometimes, the measurement of volatility on historical data is difficult, precisely because of the presence of these large fluctuations" (Bouchaud and Potters, 2000, p. 107).

As was observed, econophysicists assert that financial and economic phenomena are best described and analyzed by adopting the tools of statistical mechanics or statistical physics. The different nature of reductionism compared to the one used in economics is central here. Orthodox economic theory follows atomistic reductionism in the sense that a fundamental assumption of mainstream economic analysis is rational economic behaviour at the individual level. According to this assumption, rational economic agents have adequate (or perfect) knowledge and information about the economic reality and their needs. Thus, they are always able to choose in an optimal way, viz. to choose the best possible solution. In addition, economic agents, acting in a perfectly competitive world, are usually assumed to have stable and invariable preferences. Econophysics also follows reductionism but of a totally different kind: econophysics is based on an interactive reductionism where complex phenomena can be described through interactions between their parts (Schinckus, 2010c, p. 3818). This implies that, "econophysicists do not care about rational agent theory. By considering that 'market components' (including traders, speculators, and hedgers) obey statistical properties, most econophysicists avoid the difficult task of theorizing about the individual psychology of investors" (Schinckus, 2010b, p. 326). Econophysicists' use of statistical mechanics tools to analyze statistical properties is therefore fully justified given the above methodological framework.

This important distinction concerning the nature of reductionism has severe implications for the two research fields. In particular, econophysicists have been critics of conventional economic theory, thus distinguishing themselves from mainstream economics and finance. Some of them are quite dismissive regarding economic theory and econometrics. As the following statement indicates:

> We have no mathematical model in mind a priori. We do not “massage” the data. Data massaging is both dangerous and misleading. Econometricians mislead themselves and others into thinking that their models help us to understand market behavior (McCauley, 2006, pp. 608).

Econophysicists assert that “some striking empirical regularities (…) suggest that at least some social order is not historically contingent and perhaps is predictable from first principles” (Farmer et al, 2005, p. 38). Accordingly, one of the principal goals of this group of researchers has been to identify, measure, model and in some cases predict empirical regularities (ibid). Econophysics directs its attention to the interactions of the multiple components of the economic world that induce complex phenomena (Schinckus, 2010a). In this world, there is no guarantee that economic agents or individuals behave fully rationally, challenging thus the dominant neoclassical theory of rational choice.

In the same spirit, econophysics claims that (financial) economics adopt an axiomatic and formal framework which is inappropriate for analyzing complex phenomena like those that often occur in the financial world. Some of them adopt the position that the link to economics should be severed: “To be quite blunt, all existing ‘lessons’ taught in standard economics texts should be either abandoned or tested empirically, but should never be accepted as a basis for modelling” (McCauley, 2006, pp. 605-606).

Economics are based on an ex-ante realism stemmed from the development of abstract (a-priori) models, in contrast to a posteriori realism of econophysics which “in no way directed at the nature of hypotheses formulated ex-ante” (Jovanovic and Schinckus, 2011, p. 19). In particular, econophysicists assert that basic notions used in economic theory, such as equilibrium, representative agent, perfect rationality, etc., do not have empirical justification and emerge only from a-priori beliefs (ibid). Adopting a different way of doing scientific research, econophysicists put emphasis on constructing (empirical) models using real data about the economic and financial world. The following statement is indicative of the way that most econophysicists perceive orthodox economics:

> …by basing all economic macro-phenomena on the rational representative agent, economists implicitly set the macro-level equal to the micro-level. The consequence is that all macro-concepts (e.g. the market, systemic risk, and a financial crisis) are misunderstood in economic theory (Schinckus, 2010c, p. 3818).

There are also more “extreme” methodological stances concerning the very foundations of orthodox theory. There are papers were the assumptions of utility maximization, perfect competition and diminishing marginal productivity are deemed empirically and logically flawed (Keen, 2003 and also McCauley, 2006). This naturally raises important questions regarding the long relationship between mainstream economics and physicalism.

V. Methodological Discussion

The methodological approach of econophysics has a very important empiricist dimension: a data-driven field, it commences empirically with real stylized facts, without any prior foundation to a theoretical model. The lack of providing an adequate theoretical framework to explicate the empirical phenomena examined has been regarded as one of the flaws of econophysics (e.g. Rosser, 2008; see also Kakarot-Handtke, 2013). Furthermore, econophysicists do not pay much attention to relevant studies in economics, magnifying thus the originality of their works and the significance of their results. Similarly, sometimes their assertions of discovering universal economic laws seem to be extravagant and unreasonable. Finally, econophysicists work in areas where data sets are huge and reliable, however this is not the case for many fields of economics where data are problematic and inadequate. Consequently, important parts of economic theory may be ignored (see Rosser, 2008).

In spite of the above, econophysicists' methodological criticism towards mainstream economics and econometrics has not provoked a similar response from economists. It seems that the main line of defence against the attack is simply to ignore econophysics. A relevant study concerning the impact of econophysics to mainstream economics journal found that ''mainstream'' journals are not very open nor interested in publishing papers dedicated to econophysics (Gingras and Schinckus, 2012). Although there are a few economics journals that occasionally publish econophysics papers, the bulk of the literature is still published in physics journals.

There are only a few papers though, that focus exclusively in responding to econophysicists methodological attacks. One of the few such papers by Gallegati, Keen, Lux, and Ormerod (2006) presents the following four concerns about developments within econophysics:

1. a lack of awareness of work which has been done within economics itself,
2. resistance to more rigorous and robust statistical methodology,
3. the belief that universal empirical regularities can be found in many areas of economic activity,
4. the theoretical models which are being used to explain empirical phenomena may have difficulties and limits (Gallegati et al, 2006, p. 2).

The above four concerns also illustrate some of the econophysics' weaknesses and the possible paths that this newly-established discipline could follow in the near future in order to cope with these shortcomings

On the other hand, the majority of (econo)physics-friendly economists considered that the new discipline of econophysics not only can enrich economics, but can also contribute towards the emergence and establishment of a "new economics" that is free from some of the dogmatic hypotheses characterizing the mainstream approach (e.g. the equilibrium idea) (Ball, 2006; Bouchaud, 2009). Furthermore, some other economists are willing to see a future cooperation along interdisciplinary lines. As Barkley Rosser (2008, p. 20) pointed out, "the newer understanding of the economic system will involve a greater transcendence of our traditional disciplinary and intellectual boundaries than we have been used to in the past, just as the ongoing evolution of market systems and the ever-increasingly complex nature of their dynamics and evolving fragility challenges our understanding in the real world".

However, the reaction by the vast majority of mainstream economists seems to simply ignore econophysics and at best to engage in mild response given the explicit attack by econophysics to economic methodology. According to Gingras and Schinckus (2012), the reasons may be both methodological and sociological. The former has to do with the way that the two different fields do science (e.g. theory based vs. data driven methodology), while the latter concerns the sociological features of the two communities. The methodological gap between orthodox economics and econophysics may be regarded so huge that there is no reason for any contact due to the expected low value-added from exchanging views. The sociological aspect concerns the description of the economists' community as "a conservative, novelty-producing system since it rewards intellectual innovation only if it is directly in line with the dominant research. All new fields that are not in accordance with the scientific standards used by the mainstream are ignored" (Gingras and Schinckus, 2012, p. 134).

Apart from the above, another reason might be the methodological embarrassment that mainstream economists feel from the views of representatives of their scientific ideal. The following quotation is pointed directly to the epistemological status of economics:

> The position I now favor is that economics is a pre-science, rather like astronomy before Copernicus, Brahe and Galileo. I still hold out hope of better behavior in the future, but given the travesties of logic and anti-empiricism that have been committed in its name, it would be an insult to the other sciences to give economics even a tentative membership of that field (Keen, 2011, p. 158).

The long strive to achieve "exact science status" through the adoption of physics methods, is now challenged by physicists who are focusing on economic phenomena. Certainly, methodological criticism of mainstream economics has always been present, but it was mainly originating from heterodox economics schools, and to a certain extent, expected. It seems however, that mainstream economists are very uncomfortable of how to respond to attacks coming from their ideal model of science.

VI. Concluding Comments

The paper deals with the development of physics scientific ideal in economics starting from the vital contribution of Edgeworth to the new field of econophysics. Mainstream economic methodology has been substantially influenced by the physics methodological ideal, at least since the emergence of marginalism. The study of economic phenomena with the models and methods of physics has experienced a surge of interest through the emergence of “econophysics” in the 1990’s, which may be regarded as a new episode in the development of the relationship between physics and economics.

The paper has examined from a methodological viewpoint both the similarities and (mainly) the significant differences between mainstream economics and econophysics. Econophysicists’ emphasis to statistical mechanics rather to mechanical models, their reservations towards rational agent theory and their rejection of many standard assumptions of mainstream economics, are prime examples of such differences. Mainstream economic theorists’ response of this challenge is rather subdued, ignoring econophysics’ attack to economic methodology.

The modern reaction of orthodox economics to the challenge presented by econophysics is, however, very interesting. The physics methodological ideal has been crucial for the scientific status of orthodox economics at least since the marginalists. The recent attack to economics by econophysicists represents a rather surprising challenge by the very representatives of this scientific ideal. Thus, the lack of response by mainstream economics might indicate a certain methodological embarrassment. It seems that the long efforts to build scientific economics are now undermined by its methodological “mentors”. This development could lead to the re-emergence of the discussion regarding the epistemological nature of economics as a discipline and also to a re-examination of the concept of scientific ideal. This might be one of the least expected fruitful implications of the emergence of econophysics.

REFERENCES

Ausloos, M., Clippe, P., Miskiewicz, J. and Pekalski, A. (2004), "A (reactive) lattice-gas approach to economic cycles", *Physica A*, 344 (1-2): 1-7.

Baccini, B. (2007), "Edgeworth on the foundations of ethics and probability", *The European Journal of the History of Economic Thought*, 14 (1): 79-96.

Ball, P. (2006), "Culture crash". *Nature,* 441: 686-688.

Black, F., and Scholes, M. (1973), "The pricing of options and corporate liabilities", *Journal of Political Economy,* 81: 637-654.

Bouchaud, J. P. (2009), "The (Unfortunate) Complexity of the Economy", *Econo-Physics Forum*, 0904.0805: 1–9.

Bouchaud J. P. and Potters M. (2000), *Theory of Financial Risks. From Statistical Physics to Risk Management*, Cambridge: Cambridge University Press.

Burda, Z., Jurkiewics, J. and Nowak, M. A., (2003), "Is Econophysics a solid science?" *Acta Physica Polonica B*, 34, 87.

Bruni, L. and Guala, F (2001), "Vilfredo Pareto and the Epistemological Foundations of Choice Theory", *History of Political Economy*, 33: 21-49.

Carbone, A., Kaniadakis, G, and. Scarfone, A. M. (2007), "Where do we Stand on Econophysics?", *Physica A*, 382: xi-xiv.

Chakraborti, A., Toke, I., Patriarca, M. and Abergel, F. (2011a), "Econophysics Review: I. Empirical facts", *Quantitative Finance*, 11(7): 991-1012.

Chakraborti, A., Toke, I., Patriarca, M. and Abergel, F. (2011b), "Econophysics Review: II. Agent-based models", *Quantitative Finance*, 11(7): 1013-1041.

Collander, D. (2007), "Edgeworth's Hedonimeter and the Quest to Measure Utility", *Journal of Economic Perspectives*, 21, (2): 215-225.

Creedy, J. (1980), "Some Recent Interpretations of Mathematical Psychics", *History of Political Economy,* 12 (2): 267-76.

Dow, S. (2002), *Economic Methodology: An Inquiry,* Oxford: Oxford University Press.

Drakopoulos, S. A. (1994), "Some Implications of the New Physics for Economic Methodology", *South African Journal of Economics*, 62 (4): 198-209.

Drakopoulos, S. A. (1997), "Origins and Development of the Trend Towards Value-free Economics", *Journal of the History of Economic Thought,* 19: 286-300.

Edgeworth, F. Y. (1877), *New and Old Methods of Ethics or "Physical Ethics" and "Methods of Ethics*", Oxford: James Parker and Co. Also in Newman (ed.) (2003).

Edgeworth, F. Y. (1881), *Mathematical Psychics: An Essay of the Application of Mathematics to Moral Sciences,* London: Kegan Paul.

Edgeworth, F. Y (1885), "Methods of statistics", *Journal of the Royal Statistical Society*, Jubilee volume: 181-217.

Edgeworth, F. Y. (1887), Observations and Statistics: An essay on the Theory of Errors of Observation and the first Principles of Statistics (read 25 May 1885), *Transactions of the Cambridge Philosophical Society*, XIV(II): 138-69.

Farmer J. D., Shubik M., and Smith E. (2005), "Is Economics the Next Physical Science?" *Physics Today*, 58 (9), September: 37-46.

Fisher, I. (1892), *Mathematical Investigations in the Theory of Value and Prices,* New Haven: Yale University Press.

Gallegati M., Keen, S., Lux, T., Ormerod, P. (2006), "Worrying trends in econophysics" *Physica A*, 370: 1-6.

Gingras, Y and Schinckus, C (2012), "The Institutionalization of Econophysics in the Shadow of Physics", *Journal of the History of Economic Thought*, 34 (1):109-130.

Jovanovic, F. and Schinckus C. (2011), ''Econophysics: A New Challenge for Financial Economics?'', Working paper. University of Québec at Montréal.

Kakarot-Handtke, E. (2013), "Toolism! A Critique of Econophysics", *MPRA paper*, No 46630.

Keen, S. (2003), "Standing on the toes of pygmies: Why econophysics must be careful of the economic foundations on which it builds", *Physica A*, 324: 108-116.

Keen, S. (2011), *Debunking Economics*. London, New York, NY: Zed Books, rev. edition.

Lewin, S. (1996), "Economics and Psychology: Lessons for Our Own Day From the Early Twentieth Century", *Journal of Economic Literature*, XXXIV: 1293-1323.

Lo, A. W. and Mueller, M. T., *Warning: Physics Envy May be Hazardous to Your Wealth!* (March 12, 2010). Available at SSRN: http://ssrn.com/abstract=1563882 or http://dx.doi.org/10.2139/ssrn.1563882.

Lux, T., (2005), "Emergent statistical wealth distributions in simple monetary exchange models: a critical review". In *Proceedings of the Econophysics of Wealth Distributions*, edited by A. Chatterjee, S. Yarlagadda, and B.K. Chakrabarti, pp. 51-60, Berlin: Springer.

Mantegna R. N. and Stanley H. E. (2000), *An Introduction to Econophysics*, Cambridge: Cambridge University Press.

McCauley, J. L. (2004), *Dynamics of Markets: Econophysics and Finance*. Cambridge, UK: Cambridge University Press.

McCauley, J. L. (2006), “Response to ‘Worrying trends in econophysics”, *Physica A, 371*: 601-609.

McLure, M. (2001), *Pareto, Economics and Society: The Mechanical Analogy*, London: Routledge.

McLure M. (2010), “Pareto, Pigou and Third-party Consumption: Divergent Approaches to Welfare Theory with Implications for the Study of Public Finance”, *European Journal of the History of Economic Thought*, 17: 635-57.

Mirowski, P. (1989), *More heat than light: Economics as social physics, physics as nature’s economics*. Cambridge, UK: Cambridge University Press.

Mirowski, P. (1994), Marshalling the unruly atoms: Understanding Edgeworth’s career. In *Edgeworth on Chance, Economic Hazard and Statistics*. Lanham: Rowman & Littlefield Publishers.

Newman, P. (1987), Edgeworth, Francis Ysidro. In J. Eatwell, M. Milgate and P. Newman (eds), *The New Palgrave: A Dictionary of Economics*, vol. II. London: MacMillan, pp. 84-98.

Pareto, V. (1896-97) [1971], *Corso di Economia Politica [Cours d’ÉconomiePolitique]*. Torino: Unione Tipographico-Editrice Torinese.

Pareto, V. (1897), “The New Theories of Economics”, *Journal of Political Economy*, 5: 485-502.

Pareto, V. (1971) [1907], *Manual of Political Economy*, (transl. by A. Schwier), London: MacMillan.

Rickles, D. (2007). ‘‘Econophysics for Philosophers.’’ *Studies in History and Philosophy of Modern Physics*, 38 (4): 948–978.

Rosser, B. Jr. (2008), ‘‘Debating the Role of Econophysics’’, Working paper. James Madison University, Harrisonburg.

Samuelson, P., (1947), *Foundations of Economic Analysis*. Cambridge, MA: Harvard University Press.

Samuelson, P., (1998), “How Foundations Came to Be”*, Journal of Economic Literature,* 36: 1375-1386.

Săvoiu, G. and Iorga–Simăn. (2008), ‘‘Some Relevant Econophysics’ Moments of History, Definitions, Methods, Models and New Trends’’, *Romanian Economic and Business Review,* 3 (3): 29-41.

Schinckus, C. (2010a), ‘‘What Can Econophysics Contribute to Economics?’’ Working paper. University of Québec at Montréal.

Schinckus, C. (2010b), ‘‘Econophysics and Economics: Sister Disciplines?’’, *American Journal of Physics,* 78 (4): 325-27.

Schinckus, C. (2010c), ‘‘Is Econophysics a New Discipline? A Neopositivist Argument’’, *Physica A,* 389: 3814-3821.

Seligman, B. (1969), “The Impact of Positivism on Economic Thought”, *History of Political Economy*, 1: 256-78.

Stanley, H., Gabaix, X., Gopikrishnan, P. and Plerou, V. (2007), “Economic fluctuations and statistical physics: quantifying extremely rare and less rare events in Finance”, *Physica A*, 382: 286-301.

Stigler, S. M. (1986), *The History of Statistics*, Cambridge, MA and London: Belknap Press.

Tobin, J. (1985), “Neoclassical Theory in America: J. B. Clark and Fisher”, *American Economic Review*, 75 (6): 28-38.

Tobin, J. (1987), Fisher, Irwin, In J. Eatwell, M. Milgate and P. Newman (eds), *The New Palgrave: A Dictionary of Economics*, vol. II. London: MacMillan, pp. 369-276.

Wong, S. (1978), *The Foundations of Paul Samuelson’s Revealed Preference Theory*, London: Routledge and Kegan Paul.