Econophysics from Theory to Application: a Case Study of Iran

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***Abstract- Econophysics* is a rapidly growing field which applies the idea of physics especially statistical physics into economics especially financial economics. This paper first reviews the history, concepts, applications, and challenges of *econophysics* and then ends with an empirical investigation. Based on present paper, economists were who firstly introduced interaction between economics and physics (that we call it *old econophysics*), but the majority of the efforts in *new Econophysics* is made by physicists and the role of economists is small in this case. Physicists are not always aware of the true nature of economic theories and sometimes introduce models without any real economic theory at all. The greater degree of collaboration between economists and physicists can promote the analytical content of *econophysics* and improve the average quality of scientific endeavor in this newly established field.**

As an application of economphysic, we've applied *detrended fluctuation analysis (DFA) to Iranian foreign exchange market.* By employing Iranian Rial/US Dollar daily Forex exchange rate data from 14:03:2009 to 18:04:2010, our results suggest the exchange rate time series has long memory implying that it should be possible for speculators to extract risk-free profits by studying past Rial/Dollar series.

Keywords- Econophysics; Statistical Physics; Financial Economics; Detrended Fluctuation Analysis; Scaling Theory, Random Walk; Long Memory; Forex Market; Iran

I. INTRODUCTION

The question whether there are universal methods of scientific investigation that apply equally to nature and society was foremost in the minds of the economists who laid many of the foundations for modern quantitative economic theory in the late 1800s. Recently, there has been comprehensive effort to reintegrate natural science thinking into economics. Economics is a discipline about human behavior related with the allocation of the resources, the production, distribution and consumption of goods and services. So Economics is usually classified as a social science. But in some ways, the economics are similar to natural science. Although it has to deal with human decision, sometimes the collective behavior can be described by determinant process, at least in a statistical way. Econophysics is one of the developing fields in recent years which apply the idea of Physics especially statistical physics into economics especially financial economics. The term *econophysics* was introduced in 1995 at the second Statphys-Kolkata conference in Kolkata, by the American physicist Eugene Stanley. The official birth of the name Econophysics can be dated in 1996 to the appearance of this term in [1]. Finally the term Econophysics endorsed in 1999 by the publication of founding book [2]. The interest of physicists in economics started with the explosion of research into nonlinear dynamics, complex systems and chaos theory in the 1980s. Statistical and computational physicists have determined that physical systems which consist of a large number of interacting particles obey universal laws that appear to be independent of the microscopic details. Since economic systems also consist of a large number of interacting units, it was plausible that these laws can be usefully applied to economics. To test this possibility using realistic data sets, a number of physicists have begun analyzing economic data using methods of statistical physics [3].

The structure of the paper is as follows. After introduction in Section 1, Section 2 reviews the historical interaction between economics and physics. Section 3 introduces some of the earliest pioneers of the *new econophysics.* Section 4 presents concepts and applications of the *econophysics* and Section 5 outlines some *criticisms* of the *econophysics.* Finally the paper ends with the concluding remarks in Section 6.

II. ECONOPHYSICS: A NEW NAME FOR AN OLD REALITY

The interaction between physics and economics is very old and goes back to more than two centuries ago. From this point of view, *econophysics* may be a new name for an old reality. There is some *evidence for this statement.* The "*Inquiry into the Nature and Causes of Wealth of the Nations*", written by Adam Smith (1776), is usually considered as the beginning of classical economics. In this work Adam Smith found inspiration in the "Philosophiae Naturalis Principia Mathematica" written by Isaac Newton (1687). Especially, he based on the Newton's notion of causative forces [4]. Nicolas François Canard (1801) asserted that supply and demand were ontologically like contradicting physical forces [5]. Adolphe Quetelet (1842) confirmed the idea that physical laws could govern human behavior and also economics [6]. In the end of 19th century, Newton's theories were transformed into more modern language of analytical mechanics in the works of two mathematical physicists, Lagrange and Hamilton. In this era, the concepts of mechanics were considered as an ideal tool to be used in mathematization of economy [7]. Economists like Alfred Marshal, Leon Walras and Stanley Jevons tried to map the formalism of physics onto the formalism of economy replacing material points by economic agents, finding the analogy of "potential energy" represented by "utility" [8].

Trying to understand economic phenomena in terms of behavior of individual agents, Alfred Marshall (1890) and Francis Edgeworth (1910) were influenced by two statistical physicists, James Clerk Maxwell and Ludwig Boltzmann, and developed the concept that an economical system could achieve equilibrium like a physical system does [6]. Indeed, marginalist-neoclassical economic theory itself was essentially a result of importing nineteenth century physics conceptions into economics [9].

Paul Samuelson (1947) in his main work "Foundations of Economic Analysis" formulated the dynamic stabilities of demand-supply equilibrium following Newton's equations of motion in mechanics. George Stigler (1964) first performed Monte Carlo simulations of markets similar to those of thermodynamic systems in physics [10].

Stutzer (1994) reconciles the maximum entropy formulation of Gibbsian statistical mechanics with Black-Scholes model of asset prices, based on Arrow-Debreu contingent claims [5].

According to the above evidence, the introduction of physics applications into economics originally came from economists themselves. It should be noted that there is a fundamental difference between historical interactions of physics and economics (that we call it *old econophysics*) and *new econophysics*. Unlike *old econophysics* that economists often introduced physical approaches into economics, the majority of the efforts in *new econophysics* is made by physicists and the role of economists is negligible. If economists actively contribute to the *new econophysics* and physicists learn more about economic concepts we may find this young field more success.

III. THE EARLIEST PIONEERS OF THE NEW ECONOPHYSICS

In the literature we find great *names such as* Rosario Mantegna, Eugene Stanley, Didier Sornette, Joseph Mccauley, Hideki Takayasu, Victor Yakovenko and Jean-Philippe Bouchaud as *thinkers* of the new *econophysics*. However, the studies of economic systems using the tools of statistical physics initiated much earlier. Indeed, there were a number of great scientists such as Vilfredo Pareto, Benoit Mandelbrot, Louis Bachelier and *Maury Osborne that first posed the most* crucial concepts and tools applied in new econophysics.

If there is a single issue that unites the econophysicists, it is the insistence that many economic phenomena occur according to distributions that obey scaling laws rather than Gaussian distributions. In these non-Gaussian distributions, the tails are fatter or longer than they would be if Gaussian [11]. The initial version of such a distribution was discovered by the mathematical economist and sociologist, Vilfredo Pareto [12], in 1897. Indeed, Pareto preceded the physicists in studying distributions exhibiting scaling laws. Trying a quantitative evaluation of social inequality he collected data on income distribution in several countries including England, Ireland, Peru, several German states and a number of Italian cities. He found out that in all cases the data fit a power law relation with an exponent of $\cong 1.5$. In mathematical words, if $N(x)$ be the number of households having income greater than x, then $N(x) \propto x^{-\alpha}$. α was Pareto exponent that now called Scaling exponent. He further made the observation that values of α for all the countries observed were around 1.5. Based on these observations, Pareto proposed a universal law for income distribution [13]. However, this pioneering work of Pareto received little attention for several decades. The work on non-Gaussian distributions initiated by Pareto was revived by Mathematician Benoit Mandelbrot in 1963. He found out that financial market time series obey a complex statistical behavior which has similarities with the non-Gaussian properties of critical fluctuations in physics [14]. The Mandelbrot introduced Lévy distributions and discovered fractal and scaling behavior in financial time series that had been deeply used in *new econophysics*. Specifically, Mandelbrot's 1963 paper [15] on price fluctuations is now regarded as one of the key precursors to *econophysics*. In this paper Mandelbrot examined the price changes of cotton in the United States using various time series of daily and mid-month closing prices dating back to the beginning of the 20th century. He showed that fluctuations in cotton prices had a statistical distribution that differed from that expected of a typical Gaussian process and suggested a stable Lévy distribution to model the cotton prices[1].

In addition to Scaling theory, Random Walk theory now constitutes one of the fundamental pillars of *new econophysics*. This theory first proposed by French mathematician Louis Bachelier [17] while attempting to model the erratic motion of bonds and stock options in the Paris Bourse in 1900. He developed the mathematics of Brownian motion with his description of financial market processes five years before the famous publication of Albert Einstein on Brownian motion appeared in 1905 [14]. Bachelier's work lacks rigor in some of its mathematical and economic points. Specifically, the determination of a Gaussian distribution for the price changes was not sufficiently motivated. On the economic side, Bachelier investigated price changes, whereas economists are mainly dealing with changes in the logarithm of price. However, these limitations do not diminish the value of Bachelier's pioneering work [2]. The problem of the distribution of price changes has been considered by physicist M. F. M. Osborne. In the year 1959, he delivered a paper [18] published in Operations Research. In this paper, he replaced Bachelier's proposal of Gaussian distributed price changes by a model in which stock prices are log-normal distributed. Osborne introduced geometric Brownian motion which is an extension of Brownian motion [14].

[1] For more detail see [16].

IV. THE PRACTICAL APPLICATIONS OF ECONOPHYSICS

A system composed of a huge number of interacting subsystems is called complex system. Physicists contribute to the modeling of complex systems by using tools and methodologies developed in theoretical physics especially statistical physics. Statistical physics is a framework that allows systems consisting of many particles to be rigorously analyzed. Economic systems are among the most interesting and fascinating complex systems that might be investigated. There are some features of complex systems that are involved in economics (as a complex system). For example, complex systems often exhibit large and surprising changes that appear not to have an outside cause, instead arising endogenously. Instead of concentrating on the most frequent events, econophysicists try to study the rare or extreme events such as crashes and bubbles [19]. Mandelbrot asserted that “all my models’ ambition is to provide more effective ways to handle relatively rare events that have very strong effects”. The study of extreme events has become easier to perform since the gathering of data has been improved thanks to ever more powerful computers and the establishment of firms whose task is to collect and sell high-frequency data. In the stock market crashes and speculative bubbles, there is no sign that the arrival of news has caused the crash nor is there any link up to the dynamics of the financial fundamentals. Econophysicists argue that stock market crashes, that are often puzzling from the perspective of standard economic theory, are an entirely natural consequence of the view that economic systems, such as financial markets, are complex [19].

In econophysics the markets are viewed as complex systems with an internal microscopic structure consisting of many economic particles such as investors, traders, consumers interacting so as to generate the systemic properties. Then, the statistical physics concepts are applied to these particles [19].

In the financial economics area, econophysics focuses on models that can explain the main stylized facts of financial time series: non- Gaussian fat tail distribution of returns, long-range auto-correlation of volatility and absence of correlation of returns, multifractal property of the absolute value of returns, and so on. Comparing other economic domains, the practical application of econophysics in financial economics is very vast. Hence, the term financial Physics may be more adequate than econophysics.

Beside the distributions of returns in financial markets, econophysicists are working on the distribution of firm sizes and growth rates (Industrial economics), the distribution of income and wealth, the distribution of economic shocks and growth rate variations.

Moreover, there are various *models* recently developed by econophysicistes especially for modeling the financial markets such as Agent-based models, Lux-Marchesi model, spin model, Cont-Bouchaud model, Percolation model, Heston model, Minority game model, log-periodic model, hierarchical model, Johansen-Ledoit-Sornette model, Levy-Solomon model, Farmer model, kirman model and Kim-Markowitz model.

The majority of these models involve some crucial concepts such as scaling, universality, self-similarity, self-organization, nonlinearity, multifractality, criticality, bounded rationality and phase transition.

Also there are particular theories and methods associated with econophysics such as Random Matrix Theory, extreme value theory, Tsallis Entropy method, Monte-Carlo method, Zipf-law analysis, Rescaled Range analysis, Detrended Fluctuation analysis and Fokker-Planck approach.

V. SOME CRITICISMS OF ECONOPHYSICS

Econophysicists, by borrowing some tools from physics, have tried to analyze economic phenomena. However, despite the fact that a list of successes can be claimed in econophysics, understanding human behaviour is a more difficult thing than understanding matter, light, particles and waves [9]. Isaac Newton, after a disastrous loss of 20,000 pounds over the crash of the South Seas Bubble in 1720 said: “I can calculate the motions of the heavenly bodies, but not the madness of people”.

In fact, while in physics one can reasonably expect that the physical reality does not change in time, in economics at best we find what can be called persistence or long-run regularity of behaviour. For example, technical developments (computers, Internet) or legal regulations have a major impact on behavior of economic agents. In contrast to the material points, the economic agents are not passive. They are thinking entities, and sometimes they are very smart [7].

There are some criticisms about developments within econophysics. The first concern is that many econophysicists have a little awareness of work that the economists have done and thus sometimes claim a greater degree of originality and innovativeness in their work than is deserved. Much of the econophysics literature shows no recognition of what has been done within economics. One weakness which arises from this is the belief that empirical findings may be original, whereas they already exist in the economics literature [20]. An obvious example has been repeated articles that seem to think that economists have never been aware that some economic data may exhibit power law distributions, while as said above, An economist, vilfredo pareto, first posed this over 100 years ago. Furthermore, the econophysicists are not always aware of the true nature of economic theories and sometimes introduce models without any real economic theory at all [21]. A mutual research and effort and greater degree of collaboration between economists and econophysicists can avoid this problem.

The second criticism is that econophysicists have generally not used rigorous and robust statistical methodology. They have focused on visual tools of inspection and visually interpretable estimation procedures. Although econophysicists have certainly brought about a number of important new insights not revealed before by the battery of refined econometric tests applied by economic researchers, but there is no reason to resist the use of rigorous and more advanced statistical methods and stop a more rigorous examination of empirical data after the initial stage of exploratory data analysis [20].

The third challenging problem is that econophysicists believe that universal empirical regularities can be found in many areas of economic activity and naively search for such regularities in economics (Barkley Rosser, 2008). But empirical investigations display that a majority of universality laws discovered in physics do not extend to economics [22].

Fourth criticism is about the theoretical models which are being used to explain empirical phenomena. There is a general tendency on the part of econophysicists to develop theoretical models which are based on the principles of statistical physics. But in general the models constructed on these principles ignore absolutely fundamental features of economic reality and therefore, the results obtained with the data by such models are spurious. For example, translating statistical physics models into economics are essentially exchange-only models of economic and financial processes, which take no account of production. Capitalist economies are characterized by economic growth and a striking feature of the total income of an industrialized economy is that it expands dramatically over time. Hence, the industrialized economies are emphatically not a conservative system. Income is not conserved like energy in physics. Therefore, it is a fundamental fallacy to base economic models on a principle of conservation. Models which focus purely on exchange and not on production cannot by definition offer a realistic description of the generation of income in the capitalist, industrialized economies[2].

Finally, fifth concern is that econophysicists seem to have been eager to work in areas of economics where data sets are sparse. But it should be noted that use of the statistical Physics tools and models require a large amount of data or high-frequency data. Indeed, econophysics is applicable in areas of economics where there is a large amount of reasonably well defined data such as finance and industrial economics.

As said above, the greater degree of interaction between economists and physicists can improve the average quality of scientific endeavor in econophysics. Moreover, it is necessary to be considered chairs of econophysics anywhere in the world to physicists and economists focus on Econophysics as a central (not marginal) part of their activity.

VI. AN APPLICATION OF THE ECONOPHYSICS TO FOREX MARKET

As mentioned earlier, Scaling theory is one of the fundamental pillars of *new econophysics*. Detrended Fluctuation Analysis (DFA) is a scaling analysis method used to investigate the Presence or absence of long memory in signals [23]. This *Econophysics* technique recently used besides of econometric unit root tests such as Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test to determine whether the time series under consideration behave as a random walk and has no long memory or not. The long memory has been extensively examined as a simple way to test for predictability in financial markets. The Presence of long memory is evidence against weak-form of the Efficient Market Hypothesis (EMH) as it implies that the market does not immediately respond to an amount of information flowing into the financial market. Therefore, past price changes can be used as significant information for the prediction of future price changes [24].

The advantage of DFA over older methods is that it removes local trends through the least-squares regression fit and is relatively immune to non-stationarity [25]. Therefore, DFA permits the detection of long-range correlations embedded in non-stationary series, avoiding the spurious detection of apparent long-range correlations that are artifacts of non-stationarity [26].

In DFA technique one divides a time series *y(t)* of length *N* into *N/n* no overlapping boxes with equal size [27]. The variable *t* is discrete, *t=1,* N and N/n is an integer as well as each box contains *n* points. Let *z(t)* be the local trend function in each *n*-size box

$$z(t) = at + b \tag{1}$$

z(t) in each box can be obtained by local ordinary least square fit of the data points in that box. Then detrended fluctuation function $F(n)$ is calculated from

$$F^2(n) = \frac{1}{n} \sum_{t=kn+1}^{(k+1)n} |y(t) - z(t)|^2 \qquad k = 0,1,2,...,(\frac{N}{n} - 1) \tag{2}$$

Averaging $F^2(n)$ over all *N/n* box sizes centered on time *n* gives the fluctuations $\langle F^2(n) \rangle$ as a function of *n*. The calculation is repeated for all possible different values of *n* [27]. According to [28] a relationship between $\langle F^2(n) \rangle^{\frac{1}{2}}$ and *n* is expected as

$$\langle F^2(n) \rangle^{\frac{1}{2}} \propto n^{\alpha} \tag{3}$$

α is scaling exponent [27]. By performing a least-squares regression with $\mathrm{Log}\langle \mathrm{F}^2(\mathrm{n}) \rangle^{1/2}$ as the dependent variable and Log n as the independent one, where a straight line is observed

[2] For more detail see [20].

we find the slope of the regression which is the estimate of the scaling exponent.

α can be interpreted as follows:

- If $\alpha = 0.5$ the time series is independent and there is no correlation at all and the time series represent a random walk.
- If $0.5 < \alpha < 1$ persistent long-range correlations are present in the time series. This implies that if the series has been up or down in the last period then the chances are that it will continue to be up or down, respectively.
- If $0 < \alpha < 0.5$, anti-persistent long-range correlations are present in the time series. This means that whenever the time series have been up in the last period, it is more likely that it will be down in the next period [29].

In this study we have used daily spot Forex data between US dollar (USD) and Iranian Rial (IRR) during the period from 14:03:2009 to 18:04:2010. The data were obtained via the OANDA electronic foreign exchange service [30].

Therefore, *y(t)* is the daily spot Forex data between USD and IRR. The series contain N=400 data points, hence the variable *t* runs between *t = 1* and *t = 400*. Also, each n is one factor of *400*, for example, *n=10, n=20, n=25* and *n=40*. For each n,

we have calculated $\langle F^2(n)\rangle^{\frac{1}{2}}$ as shown in the Table 1. Using a linear regression, we have obtained the following estimate for the scaling exponent: $\alpha = 0.206$ (Fig. 1).

TABLE I THE VALUES OF $\mathrm{Log}\langle F^2(n)\rangle^{1/2}$ FOR THE PERIOD FROM

LOG N	$\mathrm{Log}\langle F^2(n)\rangle^{1/2}$
0.90309	1.627659
1	1.661136
1.20412	1.687137
1.30103	1.696034
1.39794	1.724092
1.60206	1.733712
1.69897	1.797772
1.90309	1.908227
2	1.899506
2.30103	1.927058
2.60206	1.932364

14:03:2009 TO 18.04.2010

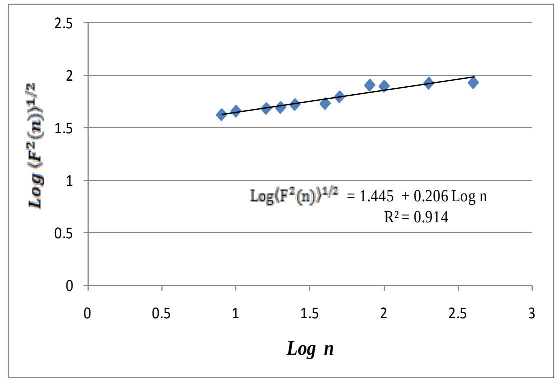

Fig.1 scaling exponent from the DFA technique for the period from14:03:2009 to 18:04:2010

Also, we have tested the null hypothesis of $\alpha = 0.5$ using Wald test to understand whether or not obtained scaling exponent is statistically different from 0.5. Wald statistic is given by $W = (\frac{\alpha - 0.5}{\sigma_\alpha})^2$ and follows a *chi-squared* distribution with one degree of freedom. α is the estimated scaling exponent and σ_α is its standard error. The critical values at the 1% and 5% significance levels are 3.8 and 6.6, respectively [31].

The calculated Wald statistic and its associated p-value were 193.99 and 0.000, respectively. This result shows that $\alpha = 0.206$ is significantly difference with 0.5 and the null hypothesis is strongly rejected.

According to Fig. 1 scaling exponent from the DFA technique shows a significant amount of anti-persistence or negative long-range correlations (α=0.206). This means that whenever the time series have been up in the last period, it is more likely that it will be down in the next period. Therefore, DFA technique provides evidence of long memory in Iranian Forex Market. As a result, it should be possible for speculators to extract risk-free profits by studying past Rial/Dollar series.

CONCLUSION

Econophysics is one of the developing fields in recent years which apply the idea of Physics especially statistical physics into economics especially financial economics. Although the term of Econophysics was introduced by the American physicist Eugene Stanley in 1995 but the interaction between physics and economics is very old and go back to more than two centuries ago. But, there is a fundamental difference between historical interactions of physics and economics that we called it *old econophysics* and *new econophysics*. Though old *econophysics*, the introduction of physics applications into economics, mostly came from economists themselves, the majority of the efforts in new *econophysics* were made by physicists.

Despite the fact that a list of successes can be claimed in Econophysics, understanding human behavior is more difficult than understanding things such as matter, light, particles and waves. In contrast to the material points, the economic agents are not passive. They are thinking entities, and sometimes they are very smart.

There are some criticisms about econophysics. Firstly, econophysicists have a little awareness of both economists' works and the true nature of economic theories so that they sometimes think of contributing a great degree of novelty in economics. Secondly, econophysicists have generally not used rigorous and robust statistical methodology. Thirdly, econophysicists believe that universal empirical regularities can be found in many areas of economic activity. Finally, they are seemingly interested in areas of economics where data sets are sparse, while the use of statistical physics tools and models require a large amount of data or high-frequency data. Anyway, the greater degree of interaction between economists and physicists can reduce these problems.

At the end, we have presented *an application* of the *econophysics to Forex market.* Detrended Fluctuation Analysis (DFA) as a scaling analysis method is used to investigate the presence or absence of long memory in signals. The long memory has been extensively examined as a simple way to test for predictability in financial markets. We have applied DFA technique to Iranian Rial/US Dollar Daily Forex exchange rate the data from 14:03:2009 to 18:04:2010.

Our results suggest negative long-range dependence or anti-persistence. Therefore, the Rial/Dollar daily Forex exchange rate has long memory, implying that it should be possible for speculators to extract risk-free profits by studying past Rial/Dollar series.

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