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TOWARDS A NEW WAY OF TEACHING STATISTICS IN ECONOMICS: THE CASE FOR ECONOPHYSICS

Christophe Schinckus[*] - *Çınla Akdere*[**]

Abstract

The selection of an appropriate way to measure data has long challenged economists. Analogies referring to scientific methods, concepts, and theories coming from the hard sciences (especially chemistry and physics) have repeatedly been used in economics since its earliest days. Today, the ambition of all university economics departments is to offer a thorough-going education in the discipline that is as scientific as possible. In fact, this is what has led academic institutions to incorporate mathematics and statistics courses into their economics departments. This statistics-based character of economics has been well documented in the literature, since it has literally shaped the "scientificity" widely promoted in the field: statistics provide an empiricist foundation to economics. This paper aims to further explore the influence of physics, in particular, on economics, focusing on the recent advent of "econophysics." We contend that the emergence of this new sub-field should be regarded as a conceptual\theoretical benefit for those teaching statistics to economics students.

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[*] Monarch Business School, Switzerland, University of Leicester, School of Business, UK, dr.schinckus@monarch-university.ch

[**] Middle East Technical University, Economics Department, Turkey, cakdere@metu.edu.tr

1. Introduction

Improving the teaching of mathematics\statistics in economics is part and parcel of instructors' desire to become more relevant to real-world concerns. A highly skilled student of mathematics could easily lose his or her motivation if unable to derive any economic meaning from a set of data. Today, economics is an ultra-mathematized profession dedicated to providing a particular meaning to the large number of economic data we can collect, thanks to computers. Since its emergence, econometrics has been progressively developed along the lines of key principles. This paper intends to explore those principles by viewing them through the lens of the likely contributions to the teaching of statistics in economics coming from a new field: econophysics.

Econometrics and econophysics are two areas dealing with the collection of data and time series. Both were born out of the communication between economics and physics. Both fields serve the purpose of arriving at an empirical economic measurement with the help of models coming from physics and statistics. But are econophysics and econometrics similar? How can econophysics bring about an improvement in the teaching of statistics in economics departments? These are the questions this paper will deal with. First, a brief history of the evolution of both fields will be presented. Afterwards, we will outline the major methodological differences between econophysics and econometrics. Finally, we will suggest how econophysics can inspire better teaching of mathematics and statistics to students of economics.

2. The Heritage of Econometrics

This section presents the key elements of the emergence and development of econometrics. (For an exhaustive history of this field, see Morgan, 1990 and Qin and Gilbert, 2001.) By emphasizing the major methodological features of econometrics, we will help to clarify the potential contribution that econophysics can make to the teaching of statistics in economics departments.

In the 1930s, the emergence of econometrics marked the first attempt to mathematize economic theorizing. At that time, the concept of utility was perceived as a mathematical metaphor of energy that played both theoretical and methodological roles. This notion of utility reinforced the development of a static theory of economic equilibrium based on a classical determinism (Ingrao and Israel, 1990); theoretically, the shift toward econometrics substituted value theory for a utility-based one. Physicists themselves participated in the coming to the fore of econometrics (Mirowski, 1989b; Morgan; 1990; Legall; 1994). The consequent paradigm shifts in economics resulting from the ferment in physics were hailed by many physicists, who came up with a new technique for representing economic phenomena that they dubbed "econometrics." Men like Ragnar Frisch, Harold Davis, Tjalling Koopmans, Henry Schultz, Trygge Haavelmo, Gerhard Tintner, Harold Hotelling, Charles Roos, and Jacob Marshak (Miroswki, 1989b, p.220) revolutionized economic theory, "changing the rules of the game for 'natural law' " (Miroswki, 1989b, p. 220).

By 1950, the econometric approach had become mainstream (Morgan, 1990, LeGall, 1999, Qin and Gilbert, 2001), although the American Institutionalist School stood in determined opposition to it. The latter sought to understand the economic behavior that produces business cycles and institutions; these economists tried to isolate fluctuating trends and represent them in barometer form. They believed that regularities were visible in the patterns of economic events, not in the statistical characteristics (i.e., average, variability, etc.) of economic cycles. In contrast, the new wave of econometric practitioners believed that the cyclical regularity of the economy was hidden within the economic statistics. Econometricians "used statistical analysis not only to determine the nature of the underlying cycle, but to establish and verify the causal relationships that made their theories as well" (Morgan, 1990, p. 69). Econometricians were testing their economic assumptions based on the data, while Institutionalists focused on presenting facts as they appeared, as opposed to testing theories.

The methodological contrast between econometrics and the Institutionalist approach generated debates, the most famous being the critique written by Koopmans (1947), who said that Institutionalists offered an inadequate treatment of data. He argued for a more rigorous use of economic hypotheses. This leading figure of the Cowles Commission (the prestigious governing body of econometric specialists) criticized the Institutionalist school for concerning itself only with the measurement of the business cycle, not its explanation. Vining (1949), of the Institutionalist school, responded by pointing out the same inadequacy in econometric works put out by the Cowles Commission. However, the two authors soon reached a consensus, emphasizing the importance of having an economic hypothesis when statistically analyzing economic data.

Econometrics was (and still is) supported by the Cowles Commission, which was founded in 1932. It promoted the mathematical formalism (Mirowski, 1989b, 1996; Morgan, 1990) that was supposed to reinforce the scientific method in economics. As an organization that legitimated and defined the scope of econometrics, the Commission soon came to be seen as a prominent institution in the field, one that attracted the backing of other major foundations (such as the Rockefeller Foundation; see Rutherford, 2011, p. 28 or

Rockefeller Foundation archives, 1903-2013). After the 1940s, the Cowles Commission became more and more statistics-oriented and its leading members (Jacob Marshak and Tjalling Koopmans) developed their famous estimation methods in line with the inference approach promoted by Pearson (1924; Neyman and Pearson, 1928).

This debate over the importance of economic theory in the handling of statistics in economics is worth mentioning for its having shaped the methodological evolution of econometrics (Morgan, 1990). Following that debate, econometrics developed into a statistical system for testing economic theory. Roughly speaking, the method used by earlier financial econometricians can be characterized by its use of linear regression, taking the following form:

$$\alpha y_t = -\beta x_t + e_t \quad (1)$$

where, y_t is the vector denoting the endogenous variables, x_t is the vector referring to the exogenous variables, and e_t is the vector characterizing the disturbances. α and β are the matrix of coefficients of variables. Although econometricians often claim they use a data-based method, we should bear in mind that the identification of the structural equations in the systems requires *a priori* restrictions on these coefficient parameters, as explained in Dharmapala *et al*. (1996, p.13):

> “These restrictions typically take the form of zero restrictions on certain coefficients showing that the corresponding variables do not enter a particular equation and are usually derived from economic theory. Such a reliance on *a priori* restrictions based on economic theory makes up one of the central methodological characteristics of econometrics."

This reference to economic theory is often explicitly mentioned in the definition of the field, as the following example shows:

> “Econometrics is the discipline in which one studies theoretical and practical aspects of applying statistical methods to economic data to test *economic theories*" (Sowey, 1983, p. 257 – our italics).

By using economic theory to set up the initial conditions of the formalized systems, the “model becomes an *a priori* hypothesis about real phenomena” (Haavelmo, 1944, p. 8). More precisely, this econometric method implies an *a priori* statement axiomatically defined but referring to economic facts[1]. Econometric works required a parameterization of the variables’ coefficient, and that step could be derived from the economic theory that econometricians wanted to test. Since this debate in the 1940s, econometrics has integrated two

[1] See Schinckus (2015) for further details on the positivist implications of this point.

key assumptions: 1) the probabilistic aspect of economic analysis and 2) the major assumption (in relation to economic theory) about the implicit existence of an equilibrium. In their estimation of time series, econometricians mainly used a Brownian motion (Gaussian framework) to characterize their idea of equilibrium, associated as it was with the existence of a main trend whose variability was described with another distribution. These methodological trends are still key points of contemporary econometrics, having led the way to particular techniques to deal with the occurrence of extreme values in econometrics series. In particular, two techniques were explored, giving rise to two literatures, allowing the Gaussian approach to persist in econometrics: the jump-diffusion and the ARCH (Autoregressive Conditional Heteroskedasticity) type models. These models arose from two different methodologies: jump-diffusion models work with extreme values by combining the statistical properties of different distributions, while ARCH models treat extreme values by modeling the residues observed in the Gaussian framework. Technically, the former proposes a mathematical solution for the analysis of extreme values, while the latter prescribes econometric processing of them.

Jump-diffusion processes were the first class of models developed by econometricians to take extreme variations into account. These models start from the premise that increments of process are independent but not identically distributed. They attempt to reproduce empirical observations by breaking stock-price movements into frequent variations of small amplitude and rare variations of great amplitude. The leptokurtic nature of price distributions is, therefore, a reflection of this double movement. This perspective results from the hypothesis that the observed distribution of prices can be divided into two: a Gaussian and a non-Gaussian distribution. The non-Gaussian distribution (referring to variations) can be described through any distribution for which the mean is finite, including a Pareto-Lévy distribution.[2]

The second category of models that take into account extreme variations, the ARCH-type models, describes the dependence of variance observed in econometric series. Specifically, ARCH-type models try to establish that the extreme values (variance) "associated with different forecast periods seem to differ over time" (McNess, 1979, p. 52). To solve this problem, Engle (1982a) introduced ARCH-type models based on statistical processes whose variance directly depended on past information. Within this framework, variance is considered a random variable with its own distribution, which can be estimated through a defined average of its past values. This model was improved

[2] Since the only statistical condition for describing this jump is the provision of a finite mean to ensure the finiteness of variability (in line with the mean variance approach).

through GARCH models by Bollerslev (1986), who showed that all last *n* returns did not influence the current variance in the same way by employing an exponentially-weighted moving average estimate in which greater weight was assigned to the more recent returns. Statistically, this past-dependence of conditional variance (which refers to the distribution of statistical errors or innovation in statistical terms) can be demonstrated through various potential statistical processes (Kim *et al*., 2008), which have generated a huge literature with a variety of time-dependence dynamics. Depending on this specific dynamic, one finds in the literature several types of ARCH models (IGARCH, EGARCH, GARCH, NGARCH, etc.)[3] Moreover, in line with the literature on jump-processes, ARCH models can register the occurrence of extreme variations within a Gaussian framework.

3. A Field Was Born: Econophysics

A new movement, known as "econophysics," was created relatively recently. This sub-field between economics and physics is said to have started with the publication of a 1996 article by Stanley *et al*. (1996) in the journal *Physica A.* However, even though the word econophysics was first coined in that year, Kutner and Grech (2008) stated that the first paper addressing this theme appeared in 1991, with Mantegna's paper on the evolution of returns in financial markets in terms of power laws.[4] This definition, which is most often cited (in Wang, Jinshan, and Di, 2004; Rickles, 2007, and Rosser, 2006) was first proposed by Mantegna and Stanley (1999, p. 2): "a quantitative approach using ideas, models, conceptual and computational methods of statistical

[3] See Francq and Zakoian (2010), Bauwens *et al*. (2006), Tim (2010), and Pagan (1996) for further details on these categories of models.

[4] It is worth mentioning that the first scholar working on power laws in time series was Benoit Mandelbrot, who mainly focused on one aspect of these laws: the statistical stationarity. The "stationary" character means that the process that causes price variations remains the same over time, but it would be erroneous to associate this stationary character with continuity of the process. This is what Mandelbrot pointed out (1997, p.138) in discussing this link between discontinuity and stationariness. "It is believed that stationariness excludes any major change and any non-banal configuration. But nothing limits the calculation of probabilities to the study of small fluctuations around a probable value." He continued to argue this point by adding that "the observation of long tails is intimately related to the symptom of discontinuity […] each time a price undergoes strong discontinuity, the new point is added to the distribution tails of price changes" (Mandelbrot 1997, p.143). In this perspective, one can consider that Mandelbrot (1963, 1965) was the first author to implement stable Lévy processes in financial economics in the 1960s. Those works led Jovanovic and Schinckus (2013) to propose a parallelism between Mandelbrot's works and econophysics. However, it is important to remember that Mandelbrot only focused on the stationary properties (which is a statistical formulation of his fractal geometry), meaning he worked only on Levy processes with a $\alpha < 2$), while econophysicists focused on power laws (unnecessary stable ones).

physics." Methodologically, econophysics should be considered an extension of statistical mechanics, one that explains the behavior and macroscopic evolution of a complex system in statistical terms (Yakovenko, 2008). Econophysics, like econometrics, is a statistics-based field that has been used by physicists to study economic phenomena. However, in contrast with econometrics, which was founded on a microeconomic perspective, econophysics views economic systems through a phenomenological analysis in which the dynamics of these systems are perceived as the macro-result of a large number of heterogeneous interactions at the microscopic level.

Econophysics focuses on the extreme variations in complex systems. The seminal paper by Mantegna (1991) compared the occurrence of extreme variations in the financial markets with the frequency of earthquakes, whose observations can statistically be described through a power law. The specificity of these patterns identified by physicists refers to their statistical form, since they can be expressed by a power law taking the form of what we call the "Lévy process." Named after the French mathematician Paul Lévy, it is a time-stochastic process with stationary and independent increments, called càdlàg paths.[5] More precisely, Lévy worked on a generalization of the Gaussian statistical framework by developing a new class of distribution, called Lévy, whose accretions are independent and stationary and follow a power law of type $P(X > x) = x^{-\alpha}$, meaning that the probability of having a variable higher than x follows a decay law. In this equation, α is the characteristic exponent of the power law (this parameter is an indicator of stability, since it refers to the sensitivity of potential variations).

This initial article written by Mantegna (1991) opened the door to an increasing number of empirical works observing power laws in socio-economic phenomena: Mantegna and Stanley (1994), Lux (2006; 2009), Bak *et al*. (1997), and Gabaix *et al*. (2003) observed that major fluctuations in financial markets could be captured through a power law, while Lévy and Lévy (1995; 2000) and Klass *et al*. (2006) confirmed the conclusion made by Pareto (1897) one century earlier by showing that wealth and income distribution could both statistically be represented by a power law. In the same vein, Amaral *et al*. (1997) explained the annual growth rates for US manufacturing companies through a power law; for their part, Axtell (2001), Luttmer (2007),

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[5] In mathematics, a *càdlàg* (French "*continu à droite, limite à gauche*"), *RCLL* ("right continuous with left limits"), or *corlol* ("continuous on (the) right, limit on (the) left") function is a function defined on the real numbers (or a subset of them) that is everywhere right-continuous and has left limits everywhere. Càdlàg functions are important in the study of stochastic processes that admit (or even require) jumps, unlike Brownian motion, which has continuous sample paths.

and Gabaix (2009) wrote that this statistical framework could also characterize the evolution of company size as a variable of its assets, market capitalization, or the number of employees. These "size models" have also been applied for describing the evolution of city size (Gabaix, 1999; Eeckhout, 2004). Dragulescu and Yakovenko (2001a, 2001b) and Sivla and Yakovenko (2005) showed that these power laws could also describe the evolution of incomes in society, while Shaikh *et al*. (2014) linked income distributions to race and gender.

Pareto's law remains important for economists in that it appears to be a good statistical approximation for empirical data whose analysis does not require an interpretation of the second statistical moment (see Schinckus, 2013). This statistical approach to dealing with data implied that the occurrence of extreme values is more frequent than a Gaussian perspective would suggest. Many Lévy processes (stable, i.e., with an exponent ≤ 2) generate infinite variance, creating non-plausible economic situations (the variance is a key parameter in economics, where it is often associated with the notion of risk—see Jovanovic and Schinckus, 2013; 2017 and Schinckus, 2013). This is why econometricians mainly rely on the stable Lévy processes as a corrective method, by combining it with a Gaussian process to capture the extreme variations of the latter.

4. Methodological Considerations

If econophysics is often compared to econometrics, it is not only due to the backgrounds of their members and their significant use of statistics but also the methodological discussions debated in the econometric literature. In this section, we will situate econophysics on the map of knowledge against the background of these fields' methodological debates. We will also point out the major differences between econometrics and econophysics.

4.1. Measurement without theory

Since the major methodological trends in econometrics have resulted from the original debate, entitled "measurement without theory," we will introduce econophysics with reference to that as well. The debate arose between econometricians and what Morgan (1990, p. 55) called "statistical economics" (i.e., the way the Institutionalists used statistics). Statistical economics as pursued by the Institutionalists might be regarded as a precursor of econophysics: this research program focused on a phenomenological description of economic systems through the identification of statistical macro-patterns. At the same time, they were criticizing the dependence of the believers in econometrics on the Gaussian distribution and its conditional approach. In accordance with econophysical works, Institutionalist economists emphasized the potential "infinite probable error" (Mills, 1927, p. 336), referring to the "fat tails" of distributions of price changes. As Mirowski (1989b) explained it, this observation was persistently ignored by neoclassical economists, while Jovanovic and Schinckus (2013) showed that it was a founding element of econophysics. As Rutherford (2011) opined, the influence of the pragmatic school (especially John Dewey) on the American Institutionalist School was substantial, and it led to contextualized treatment of statistical patterns. For their part, econophysicists see identified statistical patterns (i.e., power laws) as a signal of a universal framework. Concerning the statistical method, Institutionalists and econophysicists did not treat economic data in the same way: the former thought the regularities of data were visible in the patterns of events of the cycle but not in the statistical characteristics; the latter concentrated on the identifiable patterns and the statistical features of data.

Another main difference between econophysics and statistical economics is their perspectives on phenomena related to an emergent macro-law. The Institutionalist school saw statistical patterns as instruments for both investigation and social control: society was too complex to be associated with a natural order, so it had to be "replaced by a social order, maintained by social controls, including public opinion, belief, social institutions, and laws" (Rutherford, 2011, p.13). In this context, statistics and macro-laws were perceived as instruments for "an active intelligence guidance of social processes" (Ross, 1991, p. viii). In contrast, econophysicists explicitly associated economic systems with a self-organized system that no external actor\factor could influence. This perspective is often emphasized by econophysicists, who compare the self-organized dimension to the agent's free will, putting their approach more in line with the Hayekian idea of spontaneous order (Bouchaud, 2002; Schinckus, 2009; 2016).

4.2. Characterization of extreme values

Econometrics is often linked with the empiricist dimension of economics. However, there is still much debate surrounding empiricism in econometrics, which is sometimes presented as exaggerated in the literature (Blaug, 1992; Keita, 1992). That econometrics is based on the collection of data is not a sufficient condition to justify its being termed empirical. Strictly speaking, empiricism refers to a method in which all hypotheses and theories must be tested against observations of the natural world, rather than resting only on *a priori* reasoning, intuition, or revelation. As mentioned, econometrics is mainly based on an implicit assumption: the existence of a Gaussian trend. When econometricians detect abnormal data (data statistically outside a Gaussian distribution), they resort to data mining to ensure that all abnormal data have an expected mean equal to zero (Mandelbrot, 2004). With this perspective, they assume a specific *a priori* behavior about economic phenomena. This distinction between their method and a more data-driven one is frequently offered as the preeminent difference between econophysics and econometrics. In contrast, econophysicists do not involve themselves with data mining, strongly rejecting this kind of "*a priori*-ism" (McCauley, 2006). For econophysicists, there are no "abnormal data," but only data about reality.

This gap between econometrics and econophysics can be illustrated by considering fat tails or financial crashes. Econometricians assume that price changes obey a lognormal probability distribution, with a near-zero kurtosis (a mesokurtic distribution). This *a priori* perspective implies that massive fluctuations have a tiny probability. However, real data show a positive kurtosis and a leptokurtic distribution in which extreme events have a higher probability of occurring (Mandelbrot, 2004). By beginning with observed data, econophysicists develop models in which some extreme events, such as a financial crash, can occur.[6] This *a priori* thinking leads economists to underestimate the occurrence of financial crashes, as Mandelbrot (2004) illustrated:

> "The standard theory, as taught in business schools around the world, would estimate the odds of that final, August 31 [1998] collapse at one in 20 million–an event that, if you traded daily for nearly 100,000 years, you would not expect to see even once."

However, several financial crises were observed during the last century, and, therefore, economic theory seems unable to predict this kind of phenomenon (Kahana, 2005; McCauley, 2004). Due to this *a priori* approach and inability to describe the real world, there is in the econophysical literature an explicit rejection of those key concepts of modern economic theory that are deemed empirically and logically flawed. Most econometricians develop abstract models with many unrealistic restrictions to assure the theoretical stability of their models. They have an *a priori* model and try to shape their data to fit that model to reality.[7] This approach is rejected by econophysicists, who work on data-driven models that are meant to portray economic reality.

[6] Extreme events can be conceptualized through different econophysical frameworks—for example, as a phase transition—see Vandewalle, Boveroux, Minguet, and Ausloos (1998).

[7] For example, when Sharpe (1964) wrote his famous Capital Asset Pricing Model (widely considered a pillar of modern finance), he explained that "There are highly and undoubtedly unrealistic assumptions. However, since the proper test of a theory is not the realism of its assumptions but the acceptability of its implications, and since these assumptions imply equilibrium conditions which form a major part of classical financial doctrine, it is far from clear that this formulation should be rejected.'' (Sharpe, 1964, p.427).

Economists believe there is no outside economic reality, so they shape it themselves, whereas econophysicists are certain of this external world of economic reality they are setting out to describe.

Epistemologically, econophysics is founded on the universality of statistical properties. As mentioned above, power laws can be viewed as the macro-result of the behavior of interacting parts. These interactions are independent of the microscopic details and depend only on a few macroscopic parameters (Rickless, 2008). The power laws are emergent properties because they do not emerge causally and are not reducible to the sum of properties of the components (Kitto, 2006). There is no Gaussian aspect in the world described by econophysicsts. In using a more leptokurtic distribution, they find that extreme events have a significant probability of occurring. Potential extreme events resulting from the complex systems are then taken into account in the econophysics approach. This consideration of extreme events in economics, however, where stability is ensured by the Gaussian framework, makes the occurrence of extreme events very improbable (how then can we characterize financial crashes?).

Another fundamental separation between econophysicists and econometricians concerns the psychological assumptions about economic agents. In neoclassical economic theory, rationality appears to be fundamentally causal and explains the agents' behaviors (Lallement, 2000, Mongin, 2002). In this perspective, all macro-phenomena result from a *homopathic causality*, where the total effect of several causes acting in concert is identical to what would have been the sum of the effects of each of the causes acting alone (O'Connor and Wong, 2000). Econophysicists do not care about rational-agent theory. By considering "market components" (including traders, speculators, and hedgers) those who obey statistical properties, most econophysicists avoid the difficult task of theorizing about the individual psychology of investors (Brandouy, 2005). Only the macro-level of the system can be observed and analyzed. Economic and financial systems comprise many components whose interactions generate observable properties, such as scaling laws, which are independent of microscopic details (individual behavior). These emergent properties are based on a *heteropathic causality* because they cannot just be characterized by the sum of individual behaviors.

The intricacies outlined above imply a host of divergent pathways for the teaching of statistics within universities' economics programs. The next section will address this issue.

5. Can Econophysics Add Value to the Teaching of Statistics in Economics?

The methodological dissimilarities between econophysics and econometrics matter for what they imply about the teaching of statistics to students of economics. Two dimensions can be analyzed here: the conceptual aspect and the pedagogical one.

Regarding the first one, econophysics proposes an interesting alternative framework to deal with time series. The major differences between this field and the mainstream in econometrics can roughly be summarized by the following table:

	Econometrics	**Econophysicists**
Statistical tools	ARCH-models\Jump processes	Stable Lévy processes
Analysis	Broken down into two levels: Unconditional (Gaussian) distribution and Conditional distribution	One level of analysis: unconditional distribution based on historical data
Unconditional distribution	Gaussian	Often associated with a power law, but this is not a necessary condition
Application	To characterize the fat tails of the distribution	To describe the whole of the distribution or to characterize the fat tails of the distribution
Conditional distribution	A variety of distribution depending on the ARCH\jump model	Often associated with a power law, but this is not a necessary condition
Method	Corrective	Descriptive
Necessary condition	Existence of second statistical moment (because volatility is associated with this parameter)	None
Time dependence	Short-memory property (volatility clustering) (except FIGARCH models)	Long-memory property (Hurst exponent)
Time horizon	Short term	Long term

Source: Adapted from Jovanovic and Schinckus (2017)

In this table, which is adapted from Jovanovic and Schinckus (2017), the statistical perspective adopted by econophysicists contrasts with the one used by econometricians. The core of this difference refers to the unconditional method associated with the stable Lévy processes, which many econophysicists implement in their work. This methodological approach is impossible in econometrics because these processes imply an infinite variance, and this parameter is often associated with a key economic variable (such as risk). In their use of these models, econophysicists did not associate variance with a particular variable, meaning they were not theoretically constrained in the treatment of this parameter (see Jovanovic and Schinckus, 2017). More practically, econophysicsts produced truncation techniques to use stable Lévy processes with finite samples (see Schinckus, 2013). Although truncation techniques also exist in econometrics, they are never applied on the unconditional distribution describing time series. By developing these new truncation techniques, econophysicists extended the conceptual knowledge of statistics for economic time series. This conceptual contribution is valuable for helping students in economics to decipher certain empirical anomalies (such as the appearance of financial crashes). Indeed, the existence of financial crashes, which conflicts with the orthodoxy of the financial econometric mainstream, remains as one of the most puzzling and thus troubling mysteries for university students of economics (Becker and Greene, 2001). By working with mini-case studies, instructors of statistics in economics departments can easily illustrate the conceptual contribution of econophysics to the application of statistics.

A second aspect, mentioned above, refers to the pedagogy of statistics applied in economics. Becker and Greene (2001) identified one major problem in the understanding of statistics by future economists: the area of sampling distributions; more precisely, the difference between the law of large numbers and the central limit theorem. The former states that as the size of a sample increases, the mean of this sample converges to a true mean, whereas the latter holds that the distribution shape of a large size sample is a normal distribution. The key concepts\models of econometrics are explicitly based on the central limit theorem, but the statistical method, favored by econophysicists, is based on the law of large numbers. Teaching the statistical tools used by econophysicists to dramatize this distinction could help clarify the muddle this subject matter plunges students into.

Teaching statistics in economics also requires appropriate computers and software. Statistics software is available that integrates conceptual tools related to econophysics. *Mathematica*, for example, has proposed a "stable distributions package".[8] Aoyama *et al.* (2011) reported that the statistical software *Stata* and *SAS* could also serve for an econophysical analysis of economic data. Others are Alstott *et al*. (2014) and the script provided by Aaron Clauset on his web page, http://tuvalu.santafe.edu/~aaronc/powerlaws/, to accompany *Matlab*. *ModEco* (http://modeco-software.webs.com/ econophysics.htm), developed by an academic physicist, and *Rmetrics* (https://www.rmetrics.org/), created by the Econophysics Group at the University of Zurich–EHT Zurich, are two additional sources. The latter software is found in the university modules developed by this group (https://www.rmetrics.org/sites/default/files/2013-VorlesungSyllabus.pdf).

8 See Rimmer and Nolan (2005).

Computerized solutions based on econophysics will foster the widespread adoption of econophysics models in financial\economic practices.

6. Conclusion

In this paper, we set out to demonstrate the alternative approach offered by the field of econophysics for conceptual and pedagogical purposes in the teaching of economics. Indeed, this new area of knowledge brings new statistical tools to help instructors charged with the teaching of statistics within university economics departments. Beyond their descriptive dimension, which will make more relevant to economics students the studying of statistical analysis, these tools will go a long way toward providing enlightenment on several key pedagogical points that typically cause confusion for students in economics departments. Although the econometric mainstream is broader than that of econophysics, we claim that integrating the econophysical approach to dealing with data into the teaching of statistics in economics departments could lead to a better understanding of time-series analysis, in particular.

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