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ECONOPHYSICS: A NEW CHALLENGE FOR FINANCIAL ECONOMICS?

BY

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Financial economics was born in the 1960s. It took less than two decades for the new discipline's main theoretical results to become established, creating what is considered to be mainstream financial economics. Less than thirty years later, a new field of research called "econophysics" was created. This field aims to reinvent modern financial theory and, indirectly, financial economics.

This article proposes to study, by an historical analysis, to what extent econophysics today could constitute one of the major theoretical challenges to financial economics. It shows how these two fields have historical similarities, and analyzes how these similarities call the future evolution of financial theory into question.

I. INTRODUCTION

Financial economics was born in the 1960s. It took less than two decades for the new discipline's main theoretical results (efficient market theory, option pricing model, CAPM, and modern portfolio theory) to become established, creating what is considered to be mainstream financial economics.[1] And, although several later theoretical movements in financial economics (for example, behavioral finance and microstructure of financial markets) have tried to challenge its pre-eminence, the mainstream approach remains dominant in financial economics.[2] Less than thirty years later, a new field of research called "econophysics" was created. This field was created outside financial economics

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[1] On the history of mainstream financial economics, see Bernstein (1992), Jovanovic (2008), Melhring (2005, 2012), Poitras and Jovanovic (2007, 2010), or Whitley (1986a).

[2] In line with Frickel and Gross (2005, 208), the adjective "dominant" is used here to signify a progressive movement that urges a revival of past ideas to push the field forwards in new directions. Dominance must not be associated with the idea of truth but rather with the ability to provide a progressive evolution of knowledge. In our view, econophysics is not truer than financial economics but, as we will show, by solving old problems observed in finance, it offers a progressive perspective for financial economics.

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by physicists from statistical physics. It studies economic phenomena and, more specifically, financial markets by using models and concepts imported from condensed matter and statistical physics, a very specific area of physics.[3] In other words, econophysics is characterized by the application to financial markets of models from statistical physics that use stable Lévy processes.[4] Econophysics, which represents itself as a new paradigm, aims to reinvent modern financial theory and, indirectly, financial economics. This article proposes to study, by an historical analysis, to what extent econophysics today could constitute one of the major theoretical challenges to financial economics.

Using hypotheses and mathematical models that financial economists did not or could not develop when their discipline was taking shape in the 1960s, econophysicists are achieving better simulations of stock-price variations and thus providing more accurate forecasts than those obtained from most models used in financial economics (Roehner 2002, McCauley 2004). This situation could pose a considerable challenge to financial economics, which established itself in the 1960s and 1970s, because it claimed, among other things, to provide better forecasts than rival theories at the time. In addition, the mathematical formalisms used by econophysicists today exist in a more general mathematical framework than those currently used in financial economics. These two advantages of econophysics raise the question of whether, and to what extent, it could replace financial economics as the dominant approach in modern financial theory. Were econophysics to become dominant, its assumptions, theoretical framework, and results would form a reference, with other currents positioning themselves and their own work in relation to it.

In seeking to address this question, this article is divided into two parts.

The first part highlights the historical similarities between the emergence of financial economics in the 1960s and that of econophysics in the 1990s. We begin by describing the birth of financial economics and then the emergence of econophysics. By means of a comparative analysis, we will then show that the factors that led to the development of both financial economics and econophysics are identical: the role played by modern probability theory and by empirical data, and claims on the same scientific criteria.

These similarities call the future evolution of financial theory into question. Since econophysics has followed the same development path as financial economics, and since the empirical results and mathematical models of econophysics correspond more closely to empirical data, it is reasonable to ask whether econophysics might take over financial economics, just as financial economics took over from earlier approaches to finance in business schools. This is the question addressed in the second part. We

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[3] The influence of physics on financial economics is nothing new and has been well documented in the literature. But in spite of the theoretical and historical links between physics and financial economics, econophysics represents a fundamentally new approach that differs from preceding influences. Its practitioners are not economists taking their inspiration from the work of physicists to develop their discipline; this time, it is physicists who are studying various problems brought to light by the methods of the social sciences. On the history of econophysics, see Jovanovic and Schinckus (2013) or Roehner (2002).

[4] Of course, statistical physics cannot be reduced to the use of Lévy processes: it goes back much earlier, to the work of Gibbs and those of Boltzmann. However, econophysics focuses on this very specific class of models. The consequence is that today the literature of econophysics is (not only but) mainly based on the application of the Lévy processes to financial economics—see Gingras and Schinckus (2012) for a bibliometric study of this point.

discuss econophysics' two principal theoretical advantages: better forecasting of stock-market variations, and a more general statistical framework. We then offset these advantages by looking at the two main hindrances to econophysics' chances of challenging the dominant approach in financial economics: the poor dialogue between economists and physicists, and the reluctance of econophysicists to take up the hypotheses of financial economics. Our analysis of the advantages and disadvantages provides an historical perspective of the challenges to financial economics raised by the emergence of econophysics.

II. SIMILARITIES BETWEEN TODAY AND THE 1960S

This section provides a comparative analysis of the emergence of the two disciplines that concern us. It shows that the birth of econophysics in the 1990s follows the same pattern as the birth of financial economics in the 1960s. We will focus particularly on two major similarities: first, the role played by modern probability theory and by empirical data; and, second, the manner in which these new scientific communities were constituted.

Historical Echoes

The Birth of Financial Economics

As this section reminds us, financial economics owes its institutional birth in the 1960s to three elements: access to the tools of modern probability theory; the creation of new empirical data; and the extension of the analysis framework of economics.[5]

On the accessibility of the tools of modern probability theory. Financial economics is intimately bound up with modern probability theory, from which its emergence, main models, and results are inseparable. So close are the links that, further to the publications of Harrison and Kreps (Harrison and Kreps 1979) and Harrison and Pliska (1981),[6] some authors have suggested that economics has been dispossessed of financial theory, which has since resembled an application of modern probability theory (MacKenzie 2006, pp. 140–141). Or, as posited by Davis and Etheridge, Harrison and Pliska's article (1981) "has turned 'financial economics' into 'mathematical finance'" (Davis and Etheridge 2006, p. 114).

Modern probability theory—probability for continuous quantities in continuous time—emerged in the 1930s (Von Plato 1994) out of a number of works aimed at renewing traditional probability theory. The development of the modern version of probability theory was directly based on measure theory (Shafer and Vovk 2001). The connection was made by Kolmogorov, who proposed the main founding concepts of this new branch of mathematics.

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[5] On the emergence of financial economics, see Jovanovic (2008, 2009b, 2009a), Jovanovic and Schinckus (2010), MacKenzie (2006), and Whitley (1986a).

[6] These two publications gave a rigorous mathematical framework to definitions, hypotheses, and results that constitute the heart of modern financial theory.

From these beginnings in the 1930s, modern probability theory developed and became increasingly influential. But it was not until after World War II that Kolmogorov's axioms came to dominate this discipline (Shafer and Vovk 2005, pp. 54–55). It was also after World War II that the American probability school was born, led by Doob[7] and by Feller,[8] who proved, on the basis of the framework laid down by Kolmogorov, all results obtained prior to the 1950s, thereby enabling them to be accepted and integrated into the discipline's theoretical corpus. These 1950s works led to the creation of a stable corpus that was accessible to non-specialists. From then on, the models and results of modern probability theory were used in the study of financial markets in a more systematic manner, in particular by scholars educated in economics.

The first step in this development was the dissemination of mathematical tools enabling the properties of random variables to be used and uncertainty reasoning to be developed. The first two writers to use tools that came out of modern probability theory to study financial markets were Harry Markowitz and A. D. Roy. In 1952, each published an article on the theory of portfolio choice theory.[9] Both used mathematical properties of random variables to build their model.[10] Their work was to re-prove a result that had long been known (and that was as old as the adage "Don't put all your eggs in one basket"), using a new mathematical language, that of modern probability theory. Their contribution lay not in the result of portfolio diversification, but in the use of this new mathematical language.

From the 1960s on, a new stage was embarked upon: authors no longer limited themselves to proving past results using the mathematical formalisms of modern probability theory, but connected mathematical formalism with the main concepts of economics, particularly the concept of equilibrium, to create new theories.

The efficient markets theory,[11] which can be considered as the first theory built by financial economists, provides a good example. This theory was initially referred to as the "random walk theory." This term stresses the importance of mathematical formalism in the way issues were tackled before the discipline was constituted. The theory, first formulated by Fama (1965b), made it possible to link the mathematical model of a stochastic process with one of the keystones of economics, the concept of economic equilibrium (Jovanovic 2010). In 1970, Fama based the efficient markets theory on another mathematical concept that came from modern probability theory: the martingale model.[12] For Fama's purposes, the most important attraction of the

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[7] Doob is without question the American mathematician who has had the greatest influence on modern probability theory in the United States. On Doob, see Bingham (2005).

[8] William Feller emigrated to the United States in 1939. He was one of the first defenders of the axiomatization proposed by Kolmogorov (Shafer et al. 2005). Moreover, Feller's *An Introduction to Probability Theory and Its Application* (1950) was, like Doob's 1953 publications, one of the works that most strongly influenced modern probability theory in the United States.

[9] For a retrospective on Markowitz, see Rubinstein (2002) and Markowitz (1999).

[10] The mathematical properties of random variables are that the expected value of a weighted sum is the weighted sum of the expected values, while the variance of a weighted sum is not the weighted sum of the variances (because we have to take covariance into account).

[11] This theory is sometimes called an "hypothesis." But, from a methodological point of view, it is a fully fledged theory, even if it is used as an hypothesis in some models.

[12] The martingale model had been introduced to model the random character of stock-market prices by Samuelson (1965) and Mandelbrot (1966).

martingale formalism was its explicit reference to a set of information.[13] As such, the martingale model could be used to test the implication of the efficient markets theory that, if all available information is used, the expected profit is nil. This idea led to the definition of an efficient market that is generally used nowadays: "a market in which prices always 'fully reflect' available information is called 'efficient'" (1970, p. 383). The part played by economics in the mathematical definition of the martingale model underlines economics' key role in the creation of the structure of modern financial theory.

The creation of new empirical data. In parallel with the adoption of tools, models, and concepts from modern probability theory for analyzing financial markets, another crucial advance occurred in the 1960s: the creation of databases containing long-term statistical data on the evolution of stock-market prices. These databases allowed spectacular development of empirical studies used to test models and theories in finance. The development of these studies was the result of the creation of new statistical data and the emergence of computers.

Beginning in the 1950s, computers gradually found their way into financial institutions and universities (Sprowls 1963, p. 91). However, owing to the costs of using them and their limited calculation capacity, "it was during the next two decades, starting in the early 1960s, as computers began to proliferate and programming languages and facilities became generally available, that economists more widely became users" (Renfro 2009, p. 60). The first econometric modeling languages began to be developed during the 1960s and the 1970s (Renfro 2004, p. 147). From the 1960s on, computer programs began to appear in increasing numbers of undergraduate, master's, and doctoral theses. As computers came into more widespread use, easily accessible databases were constituted, and stock-market data could be processed in an entirely new way, thanks to, among other things, financial econometrics (Louçã 2007). Financial econometrics marked the start of a renewal of investigative studies on empirical data and the development of econometric tests.

A number of financial-econometrics studies were carried out in the 1960s, using computers. While the first empirical studies of this type date back to 1863 in France and the early 1930s in the US (Poitras 2006, Jovanovic 2009b), the results were very limited because all calculations had to be performed by hand. With computers, empirical study could become more systematic and be conducted on a larger scale. Attempts were made to test the random nature of stock-market variations in different ways (Jovanovic 2009b). Markowitz's hypotheses were used to develop specific computer programs to assist in making investment decisions.[14]

Of the databases created during the 1960s, one of the most important was set up by the Graduate School of Business at the University of Chicago,[15] one of the key institutions

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[13] By definition, a martingale model, $E(P_{t+1} | \Phi_t) - P_t = 0$, Φ_t, is a filter—that is, to use the terminology of financial economics, a set of information that increases over time.

[14] See, for instance, Cohen and Pogue (1967).

[15] In 1960, two University of Chicago professors, James Lorie and Lawrence Fisher, started an ambitious four-year program of research on security prices. They created the Center for Research in Security Prices (CRSP), which had an important group of PhD students such as Eugene Fama, Benjamin King, and Arnold Moore. Merton Miller joined them one year later, in 1961.

in the development of financial economics. The first version of this database, which collected monthly prices from January 1926 through December 1960, greatly facilitated the emergence of empirical studies. Apart from its exhaustiveness, it provided a history of stock-market prices and systematic updates.

The institutionalization of financial economics and the challenge to the dominant school of thought of the time. The third element that contributed to the institutional birth of financial economics was the integration of the analysis framework of economics (hypotheses, concepts, method, etc.) into the analysis of financial markets. This integration was the result of the formation in the early 1960s of a community of economists dedicated to the analysis of financial markets.

Until the 1960s, finance in the United States was taught mainly in business schools. The textbooks used were very practical, and few of them touched on what became modern financial theory. The research work that formed the basis of modern financial theory was carried out by isolated writers who were trained in economics or were surrounded by economists, such as Working, Cowles, Kendal, Roy, and Markowitz. No university community devoted to the subject existed prior to the 1960s.[16] During the 1960s and 1970s, training in American business schools changed radically, becoming more "rigorous."[17] They began to "academicize" themselves, recruiting increasing numbers of economics professors who taught in university economics departments, such as Miller (Fama 2008). Similarly, prior to offering their own doctoral programs, business schools recruited doctorands who had been trained in university economics departments.

The recruitment of economists interested in questions of finance unsettled teaching and research as hitherto practiced in business schools and inside the American Finance Association. The new recruits brought with them their analysis frameworks, methods, hypotheses, and concepts, and also used the new mathematics that arose out of modern probability theory. These changes and their consequences were substantial enough for the American Finance Association to devote part of its annual meeting to them in two consecutive years, 1965 and 1966.

At the 1965 annual meeting of the American Finance Association, an entire session was devoted to the necessity to rethink courses in finance curricula. Paul Wendt discussed the development of finance and explained that "a modern concept of technical market analysis is emerging which emphasizes the application of newer analytical techniques and computer technology to test traditional and new theories of stock-price behaviour" (Wendt 1966, pp. 421–422). At the 1966 annual meeting, the new president of the American Finance Association presented a paper on "The State of the Finance Field," in which he talked of the changes being brought about by "the creators of the New Finance [who] become impatient with the slowness with which traditional materials and teaching techniques move along" (Weston 1967, p. 539).[18] Although these changes elicited many

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[16] The new research path was not accepted by economists until the 1960s. Milton Friedman's reaction to Harry Markowitz's defense of his PhD thesis gives a good illustration. Friedman declared: "It's not economics, it's not mathematics, it's not business administration," and Jacob Marschak, who supervised Markowitz during his PhD, added: "It's not literature" (Markowitz 2004).

[17] See Mackenzie (2006, pp. 72–73), Whitley (1986a, 1986b), Fourcade and Khurana (2009), and Bernstein (1992).

[18] The same issues were raised in training sessions given by Financial Analysts Seminar, one of the leading professional organizations connected with financial markets (Kennedy 1966).

debates (Whitley 1986a, 1986b; MacKenzie 2006; Poitras et al. 2007; Jovanovic 2008; Poitras et al. 2010), none succeeded in challenging the global movement.

The antecedents of these new actors were a determining factor in the institutionalization of modern financial theory. Their background in economics allowed them to add theoretical content to the empirical results that had been accumulated since the 1930s and to the mathematical formalisms that had arisen from modern probability theory. In other words, economics brought the theoretical content that was missing.

The creation of a new scientific community requires that its new members share common tools, references, and problems. This was precisely the role of textbooks, seminars, and scientific journals. Those in financial economics were developed from the beginning of the 1960s with the arrival of this new generation of professors and students. The two journals that had published articles in finance, the *Journal of Finance* and the *Journal of Business*, changed their editorial policy during the 1960s. Both started publishing articles based on modern probability theory and on modeling (Bernstein 1992, pp. 41–44, 129). They also published several special issues to reinforce the new orientation and results. In 1966, the *Journal of Business* published a special issue on “recent quantitative and formal research on the stock market.” In addition to these two journals, other scientific journals specializing in financial economics were created, such as the *Journal of Financial and Quantitative Analysis* in 1965. In 1968, the last-mentioned journal published a special issue on the application of the random walk model to stock prices.

It was also during the 1960s that textbooks and collections of articles started to appear.[19] These publications also helped define and stabilize a culture shared by the members of the new community. Several seminars were also organized. The new seminars and the publications contributed to the creation of a truly homogenous community (which shared common problems, common tools, and a common language) and scientific journals and courses in universities. One of the main features of this common culture was the creation of a canonical history of financial economics during the 1960s. This history was created to support theoretical viewpoints—viewpoints that led the mainstream community of scientists to recognize financial economics as a science (Jovanovic 2008).

The Birth of Econophysics

Econophysics studies emerged in the 1990s. Their origins—like those of financial economics—lay in modern probability theory, the emergence of new empirical data, and the use of models, hypotheses, and methods taken from a discipline outside the mainstream of the time. The birth of econophysics, therefore, closely resembles that of financial economics in the 1960s.

The role of modern probability theory. From the 1980s on, modern probability theory evolved to some degree, particularly with regard to the definition of stochastic processes known as “Lévy processes” (and, more precisely, as “stable Lévy processes”). Lévy processes include many classes of stochastic processes, such as the Wiener

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[19] For instance, Cootner (1964), Fredrikson (1965), Wu and Zakon (1965), Fredrikson (1971), and Lorie and Brealey (1972) published collections of articles, while Moore (1968), Mao (1969), Jean (1970), and Fama and Miller (1972) published textbooks.

process, jump-diffusion processes, and jump stable Lévy processes.[20] Jump stable Lévy processes are characterized by the existence of small jumps in alternation with big jumps; in general, they have infinite variance. Due to their stable Lévy character, and unlike jump-diffusion models, jump stable Lévy models have infinite activity (infinite number of jumps on each time interval) and infinite variation. A specific class of jump stable Lévy processes considered by econophysicists is composed of stable Lévy processes.

Stable Lévy processes are jump processes, characterized by the stable Lévy distribution, having an α-stable law type $P\left(X > x\right) = x^{-\alpha}$ in which it is possible to observe constancy of the coefficient α. A stable Lévy distribution with $\alpha = 2$ is a Gaussian distribution; with $\alpha = 1$, it is a Cauchy distribution; and with $\alpha = 3/2$, it is a Pareto distribution.[21] Stable Lévy processes have a distribution with infinite variance, which is considered the main obstacle to the use of these processes in finance. Indeed, an infinite variance means that risk can vary considerably, depending on the size of the sample and the observation scale.

At the beginning of the 1980s, stable Lévy processes were the subject of a theoretical debate in specialist literature on statistics. These processes were essentially seen as theoretical tools (Zolotarev 1986) or as “monsters” (MacKenzie 2006, p. 108) with no real practical applications, due to their infinite variance. This theoretical characteristic added considerably to the complexity of applying these processes to observed phenomena, since the notion of variance very often refers to a well-defined empirical parameter, which is finite (risk in finance, temperature in thermodynamics, for example). Considering this situation, physicists developed theoretical solutions whose objective was to define a class of processes that was compatible with the empirical observations they had. This theoretical literature led to the development of Lévy processes with finite variance, called “truncated Lévy processes” (Schinckus 2011b).

From the 1980s onwards, stable Lévy processes were increasingly used in physics,[22] particularly in statistical physics. The latter discipline can be thought of as the continuation of thermodynamics, and the use of stable Lévy processes in this field allowed more accurate modeling of the phenomenon of turbulence. The first studies on Lévy processes applied to turbulence phenomena were those of Kolmogorov on the scale invariance of turbulence in the 1930s. This theme was subsequently addressed by many physicists and mathematicians, particularly by Mandelbrot in the 1960s when he defined fractal mathematics[23] and applied it to the phenomenon of turbulence.

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[20] A jump-diffusion process is a process generally compounded of a Wiener process (Brownian motion), characterized by the Gaussian distribution and another stochastic process (often a Poisson process). Overall, it is a Brownian motion with jumps at a specific rate dictated by the second process (Poisson process); the amplitudes of the jumps are characterized by Gaussian, exponential, or other kind of distributions. These compound processes have distribution with finite variance and a certain leptokurtic character. Also, the jump-diffusion processes have finite activity (finite number of jumps on each time interval) and finite variation.

[21] For a statistical presentation of these specific laws, see Schoutens (2003).

[22] See Frisch et al. (1994) for an analysis of the influence of Lévy processes in physics.

[23] Although modern probability theory was properly created in the 1930s, in particular through the work of Kolmogorov, it was not until the 1950s that the Kolmogorov’s axioms became the mainstream in this discipline.

Despite the extension of probability theory to thermodynamics, physicists did not seem disposed to integrate stable Lévy processes into physics (Gupta and Campanha 2002, p. 382). The reason for this methodological position—which mirrors that taken in financial economics—is that processes with infinite variance were not physically plausible (i.e., compatible with assumptions of physics).[24] As Gupta and Campanha (1999, p. 232) point out, Lévy processes "have mathematical properties that discourage a physical approach because they have infinite variance."[25] The use of Lévy processes in physics necessitated the development of truncated Lévy processes, which allowed physicists to use these processes to statistically characterize turbulence phenomena without the problem of infinite variance.[26] The first truncated stable Lévy process in physics was proposed by Zolotarev in 1986. This response of physicists to the indeterminate nature of variance paved the way for finance applications to describe the evolution of financial markets using stable Lévy processes that are not Gaussian. The first application of this statistical solution to finance was proposed by Mantegna in 1991.

Truncated Lévy processes, then, provide an opportunity to solve the problem of infinite variance observed in the application of Lévy processes in thermodynamics and finance. However, econophysicists use statistical processes in an instrumentalist manner. They are uninterested in hypotheses, preferring to focus on prediction. Of course, this kind of methodology is known in finance, where econometrics is often said to be based on the instrumentalist Friedmanian methodology (Angrist and Pischke 2008). However, unlike econometrics, econophysics is founded on a physically plausible analysis in which each statistical parameter must have a physical meaning. From this perspective, econophysicists have developed more sophisticated stable Lévy processes, giving them a statistical tool in line with a physically plausible framework (Schinckus 2011b).

The creation of new empirical data. In parallel with this application of stable Lévy processes to the study of financial markets, new statistical data were created from the 1990s as a result of the automation of financial centers.

Since the 1970s, a number of financial markets have been automated—Toronto, Paris, Nasdaq, and Euronext, for example. Today, electronic markets flood the financial sphere with accurate data in real time. The automation of markets has made it possible to record "intraday" data. Previously, statistical data on financial markets were generally made up of a single value per day (the average price). Today, by recording "intraday data," all prices quoted are conserved. The new data collected in this manner have stimulated research into distributions of stock-market variations. It is difficult to determine laws of financial data distribution with any certainty. Mitzenmacher (2004) reminds us

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[24] For example, temperature is assumed to be finite in physics, so to be physically plausible, a statistical process used in physics must generate a finite temperature.

[25] In the view of physicists, this property of physical systems is the direct result of the thermodynamic hypotheses set out by Boltzmann in 1872 when he laid the foundations of contemporary statistical mechanics.

[26] The truncation of Lévy distributions consists in normalizing them, using a particular function so that variance is finite. One can, for example, combine an untruncated Lévy process for the distribution center and explain the ends of tails using exponential distributions. On this subject, see Gupta and Campanha (2002).

of how close these laws are to the so-called exponential laws, and that the two types of law can be distinguished only by means of a large volume of data. The advent of intraday data has made it possible to build sufficiently broad samples to provide firm proof of Mandelbrot's idea that the evolution of financial markets could be characterized using stable Lévy processes such as those used by econophysicists (Kou 2008).

In this context, computer technology is presented as a tool that makes it possible to confirm with certainty the hypothesis that the evolution of prices and returns on financial markets can be characterized by a stable Lévy distribution. This growing quantification of financial information takes the form of an accumulation of data stored as temporal series, thereby making market finance "a natural area for physicists" (Gallegati, Keen, et al. 2006, p. 1).

Mantegna and Stanley (1999, p. 6), McCauley (2004, p. 7), and Burda, Jurkiewicz, and Nowak (2003, p. 3) also underline the role that computerization played in the emergence of econophysics, and above all the fact that it broadened the perspective of statistical market analysis. Now that financial markets are computerized, tens of thousands of transactions or posted quotes in a single day—time-stamped to the nearest second—can be observed (Engle and Russell 2004). Analyzing these new data sets brings new challenges, and they require new statistical tools to characterize them. More precisely, several phenomena can be detected with intraday data that are not present with monthly or daily data. The latter are generally the last prices quoted during a month or a day, or a mean of the prices quoted during a period, and, therefore, jumps in data are generally smaller and less frequent. The computerization of financial markets has, therefore, contributed to the use of new frameworks such as stable Lévy processes, which are better suited to the modeling of jumps in stock-price variations.

Computerization of financial markets and, more generally, of the entire financial sphere has had another consequence that has favored the use of stable Lévy processes with which physicists work. According to Barber and Odean (2001), the computerization of the financial sphere provides an "illusion of knowledge" to online investors, who become excessively self-confident and tend to underestimate risks. This overconfidence of investors leads them to invest more, and in a more speculative way, than they otherwise would.[27] Barber and Odean (2001) conclude that, in this way, online trading contributes to an increase in market volatility. This greater volatility has engendered more extreme variations in quotations (Jiang, Tang, et al. 2002), and, therefore, the tails of empirical distributions have become fatter. The normal law, used by almost all models in financial economics, does not allow extreme variations to be taken into account.[28] Such variations are, however, perfectly integrated into stable Lévy processes. The increase in the volatility of financial markets implying fatter tails of empirical distributions has, therefore, helped justify the use of statistical tools developed in physics that are suited to the analysis of extreme phenomena.

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[27] For instance, the development of options has increased the volatility (i.e., the price variations) of the underlying asset. Numerous studies on the effects of futures and options listing on the underlying cash-market volatility have been done. For instance, Wei, Poon, and Zee (1997) report an increase in volatility for options on OTC stocks in the USA.

[28] A device used by financial economists is to combine a normal law and a Poisson law in order to reproduce jumps.

We can see, therefore, a double contribution of technology to the emergence of econophysics: one is direct, resulting from the computerization of financial markets (better analysis and storage of data); the other, more indirect, results from financial behavior that computerization has engendered.

The institutionalization of econophysics. In less than twenty years, econophysics has earned recognition as a scientific field from academics of the hard sciences.[29] To gain this recognition, econophysicists adopted a variety of strategies for spreading their knowledge. Symposia were organized, several specialized journals created, and specific academic courses offered by physics departments to promote the scientific recognition and institutionalization of this new approach. All these strategies played a part not only in disseminating econophysics but also in creating a shared scientific culture (Nadeau 1995).

The first publications date from the 1990s. The founding article by Stanley et al., published in 1996, strongly influenced physicists and mathematicians who, suddenly, developed a non-Gaussian approach to the study of financial returns (Kutner and Grech 2008). Since 1996, sustained growth in the number of articles devoted to econophysics has been observed (Gingras et al. 2012). The increase in the number of articles published each year earned econophysics official recognition as a subdiscipline of physical sciences in 2003—less than ten years after its birth.

The first textbooks on econophysics were not far behind, the first being published in 1999 by Mantegna and Stanley (*An Introduction to Econophysics)*. The process of institutionalization was reinforced in 2006 with the creation of the Society for Economic Science with Heterogeneous Interacting Agents (ESHIA), whose objective is to promote an interdisciplinary research among economics, physics, and computer science (essentially artificial intelligence). This interdisciplinary project, supported by the creation of new journals,[30] is, therefore, aimed at the area covered by econophysics.

A further indicator of the emergence and the institutionalization of the new scientific community is the organization of symposia and workshops. The first conference devoted to econophysics was organized in 1997 by the physics department of the University of Budapest. Today, conferences and symposia dedicated to econophysics are very numerous, notable among them being the Nikkei Econophysics Research Workshop and Symposium and Econophysics Colloquium. In addition to the numerous publications about econophysics, all these regular events constitute institutional spaces that are helping to make econophysics a true scientific community.

The last major element in the institutionalization of econophysics is university education. Today, the physics departments of the Universities of Fribourg (Switzerland), Ulm (Sweden), Münster (Germany), and Dublin (Ireland) offer courses in econophysics. Since 2002, the Universities of Warsaw and Wrolcaw (both in Poland) have been offering a bachelor's and a master's degree in econophysics, respectively (Kutner et al. 2008). Finally, the University of Houston (Texas, USA) created the first doctoral program in econophysics in 2006,[31] followed in 2009 by the University of Melbourne

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[29] The growing presence of econophysics in the pages of physics journals has probably contributed to the official recognition of the field by the Physics and Astrophysics Classification Scheme (PACS): since 2003, econophysics has been an official subcategory of physics under the code *89.65 Gh*. For further information about the emergence of econophysics, see Jovanovic and Schinckus (2013).

[30] The *Journal of Economic Interaction & Coordination,* and also *Quantitative Finance*.

[31] Information on the program may be found at http://phys.uh.edu/research/econophysics/index.php.

(Australia).[32] All these programs are offered by physics departments, and courses are essentially oriented toward statistical physics and condensed-matter physics.

Similarities between the Emergence of Both Disciplines

This section underlines the similarities between the emergence of mainstream financial economics and the emergence of econophysics. The similarities suggest that econophysics is, in some respects, a continuation of financial economics.

The Role of Probability Theory and Empirical Data

As we saw in the first part, two elements strongly contributed to the emergence of both approaches: the development of modern probability theory, on the one hand; and the evolution of financial markets, which are increasingly quantitative (or digitized), on the other. In each case, these two factors acted as triggers for the emergence of an alternative approach. Let us now look more closely at this point.

In the 1960s, as explained earlier, some economists took up random processes at a time when mathematical developments had become newly accessible to non-mathematicians. The use or non-use of these new tools—modern probability theory and work on statistical data—constituted the main element setting the "new approach" against the "traditional approach" of the time: "Mathematical models, careful statistical testing of hypotheses, decision theory, the techniques of operations research, and the new and powerful tool of programming began to be applied to the finance field" (Weston 1967, p. 539).

This mathematical eolution went hand in hand with technological developments as the use of computers gradually became widespread. Computers made it possible to perform tests on empirical data (in this case, econometric tests) in order to assess the methods proposed for earning money on financial markets, particularly chartist analysis. In this respect, Rosenfeld (1957, p. 52) proved to be visionary when he suggested using computers for testing theories on a large sample.

The development of probability theory combined with finer quantification of financial markets (thanks to developments in computing) were triggering factors in the emergence of econophysics, also. As explained earlier, physicists refined Lévy laws in order to use them in physics. In particular, they developed what are known as truncated Lévy laws, which have finite variance. In this perspective, truncated Lévy laws are to econophysics what the Gaussian framework was to mainstream financial economics[33]: statistical justification of its approach and, hence, a justification of its emergence.

Once again, in the case of econophysics, computers—again in parallel with mathematical developments—contributed to the emergence of the new approach, because they made possible better quantification of financial operations. Today, electronic markets rule the financial sphere, and allow more accurate study of the evolution of the real-time data they provide (stored in the form of time series). While this type of data has been studied by economists for several decades, the automation of

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[32] http://physics.unimelb.edu.au/Community/Newsroom/News/Econophysics-scholarship-available

[33] The Gaussian framework gave birth to the first studies in financial economics (Jovanovic and Schinckus 2010).

markets has enabled intraday data providing “three orders of magnitude more data” to be recorded (Stanley, Amaral, et al. 2000, p. 339). The quantity of data is an important factor at a statistical level because the larger the sample, the more reliable the identification of statistical patterns.

Computerization of financial centers has led to the recording of huge quantities of financial data, so much so that econophysicists see finance as truly an “empirical (rather than axiomatic) science” (Bouchaud 2002). The creation of empirical databases had played the same role in the 1960s: they stimulated the application of mathematical models taken from modern probability theory and research into stock-market variations.

Thus, both financial economics and econophysics owe their emergence to the creation of new mathematics combined with the creation of new statistical data. Morgan and Morrison (1999) underlined the importance of models in twentieth-century scientific disciplines, particularly economics. Models have shown themselves to be “mediators” between theory and reality. In other words, they are neither one nor the other: “It is precisely because models are partially independent of both theories and world that they have this autonomous component and so can be used as instruments of exploration in both domains” (1999, p. 10). Analyses by Cartwright (1983), and Barberousse and Ludwig (2000), have shown that, in twentieth-century scientific disciplines at least, scientific models must be interpreted as *fiction*s. Although both financial economics and econophysics owe their emergence to mathematical modeling, they must be distinguished from one another as regards the place occupied by theory: in the case of econophysics, there is currently no theoretical explanation to give meaning to the models used.[34]

The Same Institutionalization Strategy

As regards institutionalization, econophysics is once again following the pattern observed during the emergence of financial economics: in both cases, a recognized discipline expanded towards a new field of research whose study had been hitherto dominated by another discipline. In the 1960s, economics expanded to the study of financial markets, which, at the time, was dominated by so-called “traditional” financial theory; in the 1990s, statistical physics expanded to the study of financial markets, which, at the time, were dominated by financial economics. In both cases, the new community was made up of scientists trained outside the discipline, and, hence, outside the mainstream. A kind of colonization of finance has occurred.

This colonization can also be detected in the new arrivals’ publication strategy. They began by publishing in journals of their discipline of origin to make themselves known and disseminate their results—a sort of takeover of recognized scientific journals in the discipline of origin.

In the 1960s, the newcomers took control of the two main journals specializing in finance at the time, the *Journal of Business* and the *Journal of Finance*. The aim was to modify the content of published articles by imposing a more strongly mathematical content and by using a particular structure: presenting the mathematical model and

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[34] This is one of the reasons why we describe econophysics as a scientific field and financial economics as a scientific discipline.

then empirical tests. To reinforce the new orientation, these two journals also published several special issues. Once control over these journals had been established, the newcomers developed their own journals, such as the *Journal of Financial and Quantitative Analysis* created in 1965.

Similarly, econophysicists chose to publish and gain acceptance in journals devoted to an existing theoretical field in physics (statistical physics) rather than create new journals outside an existing scientific space and, hence, structure. These journals are among the most prestigious in physics. This editorial strategy is a result not only of the methodology used by econophysicists (deriving from statistical physics) but also of this new community's hope to gain recognition from the existing scientific community quickly, on the one hand, and to reach a larger audience, on the other hand. Then they took control of editorial boards (as in the case of *Physica A* and *The European Journal of Physics B*).

The new approaches had no alternative to this "colonization strategy," because partisans of the dominant approach (and, hence, of the so-called mainstream journals) rejected these new theoretical developments in which they were not yet proficient. Gradual recognition of the new discipline subsequently allowed new specialist journals to be created, such as the *Journal of Financial and Quantitative Analysis* (1965), *Quantitative Finance* (2001), and the *Journal of Economic Interaction & Coordination* (2006), which are officially indexed under human sciences, making it possible to reach a wider readership (especially in economics).

Similar Claims regarding the Discipline's Scientificity

A final similarity is the use of the same discourse to justify the scientificity of the new approach. The emergence of both financial economics and econophysics was accompanied by particularly virulent criticism of the scientificity of existing studies. An analysis of the discourse used reveals three similar justifications: the claim of a more scientific approach, breaking with the past; belittling of the existing approach; and the claim of greater empirical realism.

The claim of a more scientific approach. In each case, proponents of the new approach challenged the traditional approach by asking its adepts to prove that it was scientific. This "confrontational" attitude is founded upon the challengers' contention that the empirical studies, the new mathematics, and methodology they use guarantee a scientificity (i.e., a way of doing science) absent from the traditional approach.[35] The challengers maintain that the scientificity of a theory or a model should determine whether it is adopted or rejected.

This confrontational approach was used by the early financial economists in their opposition to the chartists and to financial analysts.[36] As an example, James Lorie (Lorie 1965, p. 17) taxed the chartists with not taking into account the tools used in a scientific discipline such as economics. Similarly, Fama (Fama 1965c, p. 59), Fisher and Lorie (1964, pp. 1–2), and Archer (1968, pp. 231–232) presented their results as a "challenge" to chartists and financial analysts. In this debate, financial economists argued that their approach was based on scientific criteria, while chartism was based

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[35] See, for instance, Lorie (1966, p. 107).

[36] These two tendencies represented the traditional approach at the time.

on folklore and had no scientific foundation. Consequently, financial economics should supplant previous folkloric practices.

Another argument is based on the method used. Consider Fama's three articles (Fama 1965b, 1965c, 1970). All used the same structure: the first part dealt with theoretical implications of the random walk model and its links with the efficient market hypothesis, while the second part presented empirical results that validate the random walk model. This sequence—theory then empirical results—is today very familiar. It constitutes the hypothetico-deductive method, the scientific method defended in economics since the middle of the twentieth century.

As with financial economics in the 1960s, the main epistemological justification for the emergence of econophysics was the idea that the new approach was more scientific than the old. Econophysicists claim that their approach is more neutral (i.e., not based on an *a priori* model) with regard to the study of chance. They explicitly demonstrate a willingness to develop models that are, on the one hand, more coherent from a physics point of view,[37] and, on the other hand, based on "raw" observations of economic systems (Stanley, Gabaix, et al. 2008). This approach is deemed more robust and more scientific than the empirical studies carried out in financial economics (Stanley et al. 2008, p. 3),[38] and, in addition, "a claim often made by econophysicists is that their models are more realistic than those offered up by economists and econometricians" (Stanley et al. 2008, p. 3).[39] By "physically realistic models," the authors mean that econophysicists need to be able to give a physical meaning to the statistical parameters they use.[40]

Bouchaud (2002, p. 238)[41] and McCauley (2004, p. 7) further assert their position by implying that physicists are the class of scientists best placed to deal with economic and financial phenomena.

Belittling the existing approach. Justifying the emergence of a new approach involves systematically calling into question the methodology employed by the mainstream and using a specific vocabulary to denigrate its work.

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[37] That is, that accord with the theoretical principles of modeling in statistical physics—the fact, for example, that in the analysis of stationary physical systems, variance must always be finite, in accordance with the thermodynamic hypotheses (concerning the concept of heat). See Gupta and Campanha (1999).

[38] In whatever econophysicists write, they seem to be influenced by an empiricist epistemology that can also be seen as an implicit *a priori* about the world, directly inspired by a neo-positivist methodology (Schinckus 2010b).

[39] Stylized facts are the simplified presentation of an empirical finding. They often take the form of a generalization of some complicated statistical calculations, which, although essentially true, may have inaccuracies in the detail.

[40] The first reason, as we mentioned above, is the infinite characteristics of variance, which is not physically plausible because the second moment is often related to the system temperature, so infinite variance would imply an infinite temperature. The second reason why physicists rejected stable Lévy processes in physics is that these processes are based on an asymptotical argument. To characterize turbulence phenomena using stable Lévy processes, physicists had then to solve these two theoretical problems in order to fit the statistical tools to the reality they study: on the one hand, they look for a finite variance; and, on the other hand, they want to work in a (locally) non-asymptotical framework. In this perspective, they developed stable Lévy processes. See Schinckus (2011a) for further information.

[41] According to Bouchaud (2002, p. 238), finance has become an "empirical (rather than axiomatic) science.... This means that any statistical model, or theoretical idea, can and must be tested against available data, as physicists are (probably better than other communities) trained to do."

Cootner's book (1964) was one of the first publications used by the proponents of financial economics to define the discipline. In his introduction, Cootner asserted that:

> Academic studies have proven to be more sceptical about the folklore of the market place than those of the professional practitioners. To several of the authors represented in this volume the 'patterns' described by some market analysis are mere superstitions. (Cootner 1964, p. 1)

Cootner (1964) presented the first studies of the financial economists he discussed as the first scientific approach to stock-market variations, which would supplant previous practices, judged to be groundless. The method employed and the empirical test of hypotheses were also presented as a guarantee of the scientificity of the results.

Fama (1965c, p. 59) and Lorie (1966, p. 110), other emblematic figures in financial economics, denigrated traditional approaches in a similar manner. Hoffland (1967, pp. 85–88) provided a good summary of the situation:

> Folklore is a body of knowledge incorporating the superstitions, beliefs and practices of the unsophisticated portion of a society…. Folklore is distinguished from scientific knowledge by its lack of rigor…. The Dow Theory is often used as an example of a crudely formulated stock market 'theory'….

Econophysicists have proceeded in like fashion. In their work, they belittle the methodological framework of financial economics using similar vocabulary. They describe the theoretical developments of financial economics as "inconsistent … and appalling" (Stanley et al. 1999, p. 288). Despite his being an economist,[42] Keen (2003, p. 109) discredits financial economics by highlighting the "superficially appealing" character of its key concepts or by comparing it to any "tapestry of beliefs" (Keen 2003, p. 108). Marsili and Zhang (1998, p. 51) describe financial economics as "anti-empirical," while McCauley does not shrink from comparing the scientific value of the models of financial economics to that of cartoons: "The multitude of graphs presented without error bars in current economics texts are not better than cartoons, because they are not based on real empirical data, only on falsified neo-classical expectations" (2006, p. 17).

The vocabulary used is designed to leave the reader in no doubt: "scientific," "folklore," "deplorable," "superficial," "sceptical," "superstition," "mystic," "challenge."

The claim of greater empirical realism. Financial economists underlined the importance of the empirical dimension of their research from their very first publications (Lorie 1965, p. 3). They saw the testability of their models and theories as a guarantee of scientificity, and concluded that "The empirical evidence to date provides strong support for the random-walk model" (Fama 1965c, p. 59).

The same has happened in the case of the econophysicists, some of whom have insisted that it is precisely because the fundamental concepts of financial economics are "empirically and logically" (Keen 2003, p. 108) erroneous that a new, more "realistic" form of modeling needs to be developed. Here, the term "realistic" must be understood, according to econophysicists, to mean true relationship; that is, the ability to describe

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[42] With Rosser (2006, 2008a), Keen is one of the rare breed of economists who have engaged the econophysicists.

the true relationship governing changes in financial quotations.[43] This realism is, therefore, essentially *a posteriori* and in no way directed at the nature of hypotheses formulated *ex ante* (unlike economics, for example). This relationship to empiricism is very marked in econophysicists, who regularly point out that the empirical dimension is central in their work. Thus, although the "empirical data" are the same for financial economists and for physicists (financial quotations in the form of temporal series), physicists are quick to point to their "direct use of raw data," thereby criticizing the use of statistical transformations performed by financial economists to "normalize" data. Here is Mandelbrot on this point:

> The Gaussian framework being a statistician's best friend, often, when he must process data that are obviously not normal, he begins by "normalizing" them … in the same way, it has been very seriously suggested to me that I normalize price changes. I believe, quite to the contrary, that the long tails of histograms of price changes contain considerable amounts of information, and that there are a number of cogent reasons for tackling them head-on. (1997, p. 142)

McCauley directly attacks this practice used by financial economists, explaining,

> We [econophysicists] have no mathematical model in mind *a priori*. We do not 'massage' the data. Data massaging is both dangerous and misleading.... Economists assume a preconceived model with several unknown parameters and then try to force-fit the model to a nonstationary time series by a 'best choice of parameters.' (2006, p. 8)

This methodological position is widespread among econophysicists, who work in the spirit of experimental physics in contrast to standard methods in economics. This empirical perspective is also justified, in the view of econophysicists, by the evolution of financial reality. The computerization of financial markets has led to better quantification of financial reality, which should now be studied as an "empirical science" (Bouchaud 2002, McCauley 2004). This radical viewpoint espoused by some econophysicists has an element of naivety. Indeed, in a sense, any sampling method is a massaging of data. Nevertheless, this viewpoint has led econophysicists to a better consideration of extreme values, while such values are considered as errors by the majority of financial economists.[44] However, econophysicists seem to forget that all statistical data are embedded in a theory. By developing only physically plausible frameworks, econophysicists also appear to have some *a priori* beliefs about the world. Indeed, for econophysicists, there are no "abnormal data," but only data about reality. From this point of view, whatever econophysicists write, their empiricist methodology can also be seen

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[43] Although they are mainly focused on instrumental prediction, econophysicists often claim they deal with essential relationships existing in financial phenomena (McCauley 2004).

[44] The way the CRSP database was created provides a good example of apriorism from financial economists: "Rather than coding and punching all prices twice and then resolving discrepancies manually, we found a better procedure. We know that the change in the price of a stock during one month is very nearly independent of its change during the next month. Therefore, if a price changes a large amount from one date to a second date, and by a similar amount in the opposite direction from the second date to a third, there is a reason to believe that at the second date the price was misrecorded. A 'large change' was rather arbitrarily taken to mean a change in magnitude of more than 10 per cent of the previous price plus a dollar" (Lorie 1965, p. 7).

as an implicit *a priori* assumption about the world directly inspired by a neo-positivist epistemology (Schinckus 2010b, 2011b). In a sense, no way of collecting data can ever be totally neutral, because all data are necessarily the result of a specific process (Schinckus 2010a).

III. COULD ECONOPHYSICS DOMINATE TOMORROW'S FINANCIAL THEORY?

Our first part has shown that the creation of econophysics followed the same path as the creation of financial economics, which subsequently came to dominate financial theory. Furthermore, financial economists in the 1960s and econophysicists in the 1990s and 2000s justified the emergence of their approach using the same arguments. The fact remains that financial economics is today a well-established scientific discipline, particularly thanks to its links with economics. Econophysics, on the other hand, still occupies a marginal position in modern financial theory. However, the similarity in the emergence of these two theoretical approaches raises the question of whether econophysics could emerge as the dominant approach in finance, just as financial economics did several decades earlier.

Our point is not to suggest that history repeats itself, but that the way a dominant approach is created leads to the establishment of specific relations with theories, models, and hypotheses (for instance, the discrepancies that will be considered as anomalies). More precisely, defenders of an established approach cannot be indifferent to the emergence of a new community that follows the same path to fight for its place in the scientific community. This second part analyzes this question in detail, examining the strengths and weaknesses of econophysics in its struggle to challenge financial economics.

Strengths that Could Help Econophysics Supplant the Mainstream Approach

Econophysics has two main strengths to help it become dominant: it explains empirical facts that are not explained by today's mainstream financial economics; and it uses a mathematical framework that represents a continuation of the models used by financial economists, but is more general. These two elements are crucial to the question we are examining, because of the role they played in the emergence of both these scientific approaches.

Better Prediction of Empirical Facts

Econophysics' first strong point is its ability to explain empirical facts for which financial economics fails to account. As the work of Kuhn (1962) showed, the emergence of a new approach can be justified by its ability to provide answers to the anomalies of the established approach.[45] In order for a new approach to establish itself as the new reference point for a discipline, it must not only generalize the existing results of the

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[45] We use the term "anomalies" here to qualify the difference between empirical observations and theoretical predictions.

old approach but must also better explain observed empirical facts (including those not explained by the old approach).

This question is deeply embedded in the history of financial economics. Indeed, the emergence of new empirical data and new statistical and mathematical models has regularly led financial economists to transform discrepancies between predictions and observations into anomalies. As we have seen, before the 1960s, statistical records of stock prices were monthly data; the CRSP then began collecting daily data. This changed the manner in which observations were treated. In 1978, just a few years after mainstream financial economics created the efficient-market hypothesis, Jensen pointed out that

> in a manner remarkably similar to that described by Thomas Kuhn in his book, *The Structure of Scientific Revolutions*, we seem to be entering a stage where widely scattered and as yet incohesive evidence is arising which seems to be inconsistent with the theory. As better data become available (e.g., daily stock-price data) and as our econometric sophistication increases, we are beginning to find inconsistencies that our cruder data and techniques missed in the past. It is evidence which we will not be able to ignore. (Jensen 1978, p. 95).

Econophysics emerged in the wake of similar developments: the creation of new data (intraday data) and the new mathematical tools (truncated Lévy processes in particular) allowed more accurate observation and then transformed several discrepancies into anomalies. Consequently, econophysicists highlight the existence of a number of empirical facts that are not explained by mainstream financial economics and constitute anomalies. In view of the fact that prices on financial markets change more frequently and in a more orderly manner than is supposed by the Gaussian framework on which financial economics was established, econophysicists use α-stable Lévy processes directly to describe the evolution of financial data. Because econophysicists had their own theoretical goals (making Lévy processes compatible with a physically plausible approach), they developed a statistical framework outside the traditional approach. Doing so allows them to address a number of empirical facts that the traditional approach of financial economists cannot explain because it uses a Gaussian framework.[46]

The main empirical facts to which econophysics proposes answers where financial economics is unable to are “fat tails,” “volatility persistence,” and “volatility clustering.”

In the 1960s, during the creation of mainstream financial economics, Mandelbrot (1963, 1965) and Fama (1965a) drew attention to the high number of extreme events in finance and, hence, to the leptokurticity of empirical distributions, which have fat tails. At the time, these authors proposed describing empirical distributions with stable Lévy processes. The distributions associated with stable Lévy processes are approximately bell-shaped but they assign greater (than Gaussian) probability to events in the center and at the ends of the tails. However, in 1965, Fama (1965a, p. 416) pointed out that the infinite variance of stable Lévy processes is meaningless in financial economics, since this statistical parameter is associated with the concept of risk, and

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[46] Jovanovic and Schinckus (2013) explain that the Gaussian approach has played a key role in the construction of the mainstream, and, until now, stable Lévy processes have not allowed such results.

deplored the fact that no computational definition yet existed for evaluating this parameter. Financial economists did not have the statistical tools that would allow them to describe empirical distributions with a stable Lévy framework. Another reason why fat tails had not been studied lies in the difficulty of clearly identifying statistical processes with weekly or daily data (Mitzenmacher 2004). In this respect, the availability of intraday data since the 1990s has favored the identification of stable Lévy processes and has subsequently stimulated research into these processes. Since the 1990s, new statistical tools have been developed with the aim of creating stable Lévy processes with finite variance. Econophysical works are directly in line with these new statistical tools.

The second main empirical fact to which econophysics proposes answers is volatility persistence.[47] In the 1970s, when financial economists created their theoretical framework, they did not have the econometrical tools that could help authors to identify a persistence of volatility. According to this framework, which is based on the Gaussian distribution, there is no memory between stock-market returns. Starting from the 1980s, econometrical tools have been proposed, with the development of ARCH family models (Engle 1982) demonstrating that volatility has slowly decaying autocorrelations showing a dependency between stock-market returns. Later, Schwert (1989) showed this persistence of volatility in a different statistical context.

The last main empirical fact is volatility clustering.[48] In a Gaussian framework, one could expect to see a very uniform time distribution of large and small fluctuations. In 1981, an original use of a martingale model led Shiller to observe several periods of large fluctuations and periods of small fluctuations that are not consistent with the Gaussian framework. In other words, periods of intense fluctuations and low fluctuations tend to cluster together (Shiller 1981b, 1981a). Shiller's works generated much debate and favored the emergence of new fields calling neoclassical finance into question—behavioral finance, for example (Schinckus 2009). Econophysicists' tools make it possible to put forward answers to this empirical fact.

To answer these anomalies, econophysicists base their analysis on Lévy processes that are better adapted to the empirical data available today. Lévy's α-stable regimes are processes whose accretions are independent and stationary,[49] and follow an α-stable law type $\Pr\{X > x\} = x^{-\alpha}$ in which it is possible to observe constancy of the parameter α. In their Paretian form, these regimes have $\alpha < 2$, and in these cases, it can be shown that variance is infinite.[50] As Belkacem (1996, p. 40) emphasized, "from a practical point of view, stable distributions are able to explain the thick distribution tails observed in empirical distributions of asset profitability rates." A similar argument is found in the writings of Tankov (2004, p. 13), who added that these processes are particularly interesting in financial economics because they allow discontinuities in the evolution of asset

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[47] Clegg (2006) discusses the integration of this empirical fact by econophysics in greater detail.

[48] See Sornette (2003) for a precise presentation of the response to this anomaly proposed by econophysicists.

[49] The "stationary" character means that the process causing 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.

[50] For $\alpha < 1$, the variance but also the mean are also theoretically infinite (or undefined).

returns to be taken into account. This means that these processes are candidates for explaining the leptokurticity of financial data.

The analysis of these empirical facts proposed by econophysicists is essentially empirical itself, and points to econophysics' predictive capacity. Above all, the solutions allow a better statistical understanding of the phenomenon of financial data variability. As pointed out by Shiller (1981b), this phenomenon has been underestimated by neoclassical finance's theoretical framework.

The integration of empirical facts unexplained by financial economics into the (more generalized) theoretical framework developed by econophysicists is, thus, an argument in favor of a shift in mainstream financial theory.

A More General and More Complete Probabilistic Framework

Econophysics' second strong point in its bid to become the dominant approach is the use of statistical models that generalize those used in financial economics.

Financial economists mainly use the Gaussian framework in order to characterize financial uncertainty. Four reasons can be cited to explain the success of the Gaussian framework: the historical development of financial economics (Jovanovic 2008, Jovanovic et al. 2013),[51] simplicity (only two parameters are needed to describe data), the notion of normality (which can refer to the key concept of economic equilibrium), and, above all, statistical justification, which refers to one of the most fundamental theorems[52]: the central-limit theorem (CLT), which states that the sum

$$Z_n \equiv \sum_{i=1}^{n} x_i$$

of n stochastic variables x that are statistically independent, identically distributed,[53] and with a finite variance converges when $n \to \infty$ to a Gaussian stochastic process (Feller 1971).

For econophysicists, the Gaussian framework is the first step towards describing uncertainty in science. This first step can be generalized to a savage uncertainty "without normality" (Mandelbrot 1997, p. 66). This generalization is based, on one hand, on Lévy's work (1924) on random processes, and, on the other hand, on the generalized central-limit theorem developed by Gnedenko and Kolmogorov (1954). In accordance

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[51] Jules Regnault, in 1863, was directly influenced by Adolphe Quételet's work on the application of normal distribution to social phenomena (Jovanovic 2001, 2006). Bachelier (1900), whose work was clearly influenced by Regnault's (Jovanovic 2000, 2009b, 2012), retained a Gaussian description of the evolution of variation in the price of assets for demonstrating the equivalence between the results obtained in discrete time and in continuous time. Similarly, all the empirical work that emerged from the 1930s onward (Cowles 1933, Working 1934, Cowles and Jones 1937, Kendall 1953) used this Gaussian framework because at the time it was impossible to use other kinds of statistical distribution. Indeed, all non-Gaussian observations and "white noise" were characterized through a Gaussian standardization.

[52] The first fundamental theorem is The Law of Large Numbers (Tijms 2004).

[53] A generalization of the theorem for variables that are not identically distributed (but always with a finite variance) was developed by Gnedenko and Kolmogorov (1954).

with this generalization, the sum of random variables following Lévy laws, distributed independently and identically, converge towards the stable Lévy law having the same parameters. This generalization of the central-limit theorem justifies and provides a statistical foundation for the use of Lévy laws to characterize complex phenomena.[54] Lévy's work proposed a generalization of several known distribution laws in the form of a family of random variable distributions notated as $S_{\alpha,\beta}(\mu,\gamma)$.[55] By basing their approach on Lévy processes, econophysicists propose models that encompass all stochastic processes, such as Gaussian processes and Poisson processes.

By making use of stable Lévy processes, econophysics offers a more general theoretical framework than financial economics, which uses Gaussian distribution.[56] From this perspective, the models of financial economics are merely particular cases,[57] and the statistical tools used by econophysicists make possible technical integration of the Gaussian statistical framework on which mainstream financial economics is based. As a generalization of the Gaussian framework, the α-stable framework retains the fundamental properties (fractality and auto-affinity) of the Gaussian framework. There is, thus, mathematical continuity in the models used by financial economists and those used by econophysicists. This continuity had been advanced in the 1960s by Mandelbrot and Fama at the very beginning of the creation of mainstream financial economics. This attempt was not developed because of the theoretical meaninglessness of the hypothesis of infinite variance. Several paths have been explored by financial economists since the 1970s but none dropped the Gaussian framework (Jovanovic et al. 2013).[58] Today, the evolution of mathematics developed by econophysicists allows the development of a Markowitz portfolio theory, a generalized CAPM in an α-stable framework (Belkacem 1996, Tankov 2004), and the development of a Black and Scholes option-pricing model in an α-stable framework (Huang and Wu 2004). Such a characteristic would also make it possible to preserve the concept of market efficiency, even if new risk-analysis parameters were to be introduced. As Fama pointed out (Fama 1965c), the concept of efficiency did not necessarily imply the Gaussianity of accretions.

The generalization used today by econophysicists is, thus, a strong point. Moreover, it renders the first attempts of financial economists such as Fama (1963) and Mandelbrot (1965) viable. These first attempts have been enhanced by the purely mathematical framework developed by Harrison and Pliska (1981). Indeed, by proposing a non-economic model in finance, Harrison and Pliska provided an entry point for an evolution of modern finance less based on economics. As a result, from a mathematical viewpoint, the models developed by econophysicists continue from where those developed by financial economists left off. The challenge for the future of econophysics will be to

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[54] The central-limit theorem, according to historians of statistics, provided the main argument for the use of the Gaussian framework for the study of varied phenomena.

[55] As Schoutens (2003) makes clear, the family of α-stable distributions identified by Lévy appears to be the general form of a number of statistical laws known as the normal law $S_{2,0}(\mu,\gamma)$, Cauchy's law $S_{1,0}(\mu,\gamma)$, Pareto's law $S_{3/2,\beta}(\mu,\gamma)$, and Lévy's law $S_{1/2,1}(\mu,\gamma)$.

[56] To allow comparison of the various models developed by econophysicists, Bucsa, Jovanovic, and Schinckus (2010) propose a generalized formula that can be used to unify the work of these research fields.

[57] Economists and financiers have long been interested in the leptokurtic nature of price distributions. See Louçã (2007, p. 219), Jovanovic (2009b), and Jovanovic et al. (2013).

[58] For instance, Merton's (1976) model on jump processes.

show that the models proposed by econophysicists can be integrated into this mathematical framework developed by Harrison and Pliska.[59]

Limitations Hindering Econophysics from Becoming the Dominant Approach in Finance

As we have explained, econophysics was born outside financial economics, and it is today achieving institutional status with its own prestigious, intellectual actors, awards, journals, conferences, academic programs, and departments. This last section explains that in spite of all this, the results, models, and hypotheses of econophysics have so far failed to break into the mainstream of financial economics, even if, since the 1990s, financial economists have progressively begun to publish papers related to Lévy processes.[60]

Indeed, although econophysics has undeniable advantages to help it establish itself as the new dominant approach in finance, two major limitations work against this eventuality: first, the virtual absence of discussion between financial economists and econophysicists; and, second, econophysicists' non-use of financial economics and mathematical-finance hypotheses.

The Virtual Absence of Discussion between Financial Economists and Econophysicists

Although econophysicists explicitly position themselves in relation to financial economics, it has to be noted that the response of economists to their criticisms has been, for all intents and purposes, non-existent. Some economists have pointed out the limitations of the econophysics approach (Gallegati et al. 2006),[61] provoking a virulent response from one of the leading lights of econophysics (McCauley 2006). Aside from this brief exchange of communication, real theoretical debate between econophysicists and economists has so far seemed difficult. The sometimes severe criticisms made by econophysicists of the models and hypotheses used in financial economics have apparently failed to convince economists of the need to engage in theoretical discussions. One feature in particular explains the problem: econophysics' framework is not directly compatible with that of financial economics, and econophysicists do not take

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[59] As we mentioned earlier, none of the studies by financial economists dealing with Lévy processes focused on stable Lévy processes or had any connection with the methodology used by econophysicists.

[60] It is essential to point out that Lévy processes include many classes of stochastic processes, such as the Wiener process, jump-diffusion processes, and jump stable Lévy processes (Variance Gamma Process, Madan 1990; Generalized Hyperbolic Process, Eberlein 1995; CGMY process, Carr et al. 2000). As a result, economists and econophysicists may use the same word for quite different models. While economists use the term "Lévy process" to define (non-stable) jump-diffusion and (non-stable) jump stable Lévy models, econophysicists use this word to define stable Lévy processes. Moreover, all papers dedicated to Lévy processes in financial journals have been written by mathematicians or financial economists and not by physicists. The semantic difference is a source of debates between econophysicists and economists. The first often claim that they offer a new perspective on finance, while the latter consider that this approach is an old issue in finance. The point is that these two categories of specialists are not talking about the same thing: econophysicists use stable Lévy processes, while economists abandoned this kind of processes in the 1970s (Jovanovic and Schinckus 2013).

[61] This critique was published in a physics journal by economists who do not themselves subscribe to the mainstream approach of financial economics.

this point into account. Indeed, because econophysicists' focus is on mathematical development, very few of them have attempted to make their models compatible with the framework and hypotheses of financial economics.[62] One who has made the attempt to connect econophysics with financial economics is Bouchaud—see, for instance, Bouchaud and Potters (2003).

As a result, the leading economics and finance journals make very few references to the work of econophysicists. Gingras and Schinckus (2012) looked at the ten leading authors in econophysics, between 2002 and 2008, and found 401 references to these authors in the main economics and finance journals as against 2506 in the main physics journals. This disparity highlights the fact that econophysics is not considered the central issue in economic journals.[63]

One might assume that, rather than economists "rejecting" econophysicists, it is more a case of the latter's having developed their models outside the financial economics' framework, and, hence, considering that they had no need to publish in mainstream economic journals or adapt their methodology and viewpoints to those of financial economists. With the evolution of the two disciplines as analyzed in the first part of this paper, this is no longer the case. First, we have shown that econophysicists have created new journals (*Quantitative Finance* and *JEIC*) in economics (and not in physics) in order to reach financial economists and an audience outside econophysics. Second, since econophysicists work on the same phenomena as economists, we should expect them to attempt publication in economics journals. To test this hypothesis, we conducted an informal survey, sending a questionnaire to twenty-seven leading econophysicists (included as source authors in our analysis) about the degree of openness of economics journals to econophysicists. To the question "Have you submitted a paper to a ranked journal in economics?", a large majority of authors replied "yes." When authors were asked to give the main reasons[64] why their paper was rejected, they replied that referees in economic journals often have difficulties with the topic or/and the method used in their paper. Although based on a small sample (but including the central figures of econophysics), these results strongly suggest that economic journals are indeed reluctant to publish papers dedicated to econophysics. The lack of discussion between the two approaches could explain this situation, because no bridges are built between them.

Nevertheless, in 2008, the *Journal of Economic Dynamics and Control* published a special issue entitled *Applications of Statistical Physics in Economics and Finance.* Doyne Farmer and Thomas Lux[65] were guest editors for this special issue, articles for which were written by economists and physicists. This special issue aimed to "overcome the lack of communication between economists and econophysicists"

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[62] In addition, as Rosser (2008b, p.10) points out, econophysics' models "are only of exchange and do not allow for production, and they often confuse basic concepts such as transactions and income, this latter especially for models of income and wealth distribution."

[63] For example, only three references to key writers on econophysics are found in the leading journal of financial economics, the *Journal of Finance (*source: *Web of Science).*

[64] They had to choose between five reasons for their rejection and were invited to comment on their choices: 1) the topic of the paper, 2) the assumptions used in the paper, 3) the method used in the paper, 4) the results of the paper, or 5) other reasons.

[65] The first is a physicist and the second an economist; both were among our source authors.

(Farmer and Lux 2008, p. 3). As these authors pointed out in their editorial, there is “a lack of communication between physicists and economists. Physicists are perhaps the only group of scientific professionals who are even more arrogant than economists, and in many cases the arrogance and emotions of both sides have been strongly on display” (Farmer and Lux 2008, p. 3). In order to overcome the gap between the two camps, this special issue published twelve articles dedicated to econophysics, written by authors from the fields of economics and physics. Despite this first attempt at dialogue, debate has still not yet really begun.

Among the few economics journals to publish articles about econophysics is *Journal of Economic Behavior & Organization,* which recently broadened its editorial line to encompass the problems of complexity in economics (and consequently published several studies dedicated to econophysics). Other journals officially indexed under economics that regularly publish articles on econophysics include *Quantitative Finance*, created in 2002, and *Journal of Economic Interaction and Coordination,* created in 2006. The creation of these two journals, both of which have an editorial team made up largely of econophysicists, appears to be a strategy for the dissemination of econophysics, the aim being to make the approach better known to an audience of economists (Gingras et al. 2012).

The lack of dialogue can also be connected with the closed nature of economics.[66] Whitley (1986b) portrayed economics as a “reputationally controlled work organization” characterized by a strong and monolithic standardization of research. He explained that economics is a “partitioned bureaucracy” whose segmentation into several subfields allows it to marginalize all anomalies or empirical contradictions of the mainstream. Economics appears 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 simply ignored. In this perspective, the conceptual basis of econophysics could come only from outside the field of economics and be promoted by physicists who saw that the kind of distribution behind economic and financial phenomena, which are a collective response of the interactions of a large number of agents, are analogous to the distributions observed in condensed-matter physics as the result of the collective interactions of a large number of atoms. Starting from that analogy, they applied the methods of statistical mechanics, which explain the emergence of these distributions, to the case of economic and financial behavior. Such a move radically transforms the understanding of economics, as the usual Gaussian framework is replaced by a Lévy framework whose statistical properties are very different and are not necessarily consistent with the conceptual foundation of mainstream economics, based on equilibrium. Moreover, while economic theory is based on an atomistic reductionism in which reality must be explained in terms of rational representative agents, econophysics focuses on the interactions that give rise to complex phenomena

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[66] Pieters and Hans (2002) explored intra- and interdisciplinary communication of economics journals by means of citations analysis. They showed that the first tier of economics journals did not cite articles published in journals of management, marketing, anthropology, or psychology between 1995 and 1997.

that can be described through interactions between their parts.[67] These conceptual differences, coupled with the difference in disciplinary training between economists and econophysicists, have contributed to the development of econophysics as a separate scientific culture whose roots stayed in physics instead of developing out of economics, like other new specialties such as behavioral finance and experimental economics.

There is, thus, a dynamic of repulsion between economics and econophysics: as Whitley observed, "economics has a strong hierarchy of journals" (Whitley 1986b, p. 192), and researchers who do not conform to the dominant standards are bound to publish outside that core and, therefore, be seen as irrelevant to the core, and consequently forced to publish in new journals not recognized by the mainstream of the discipline. Whereas this tendency could have given rise to a new speciality among the social sciences, the fact that the tools of econophysics were imported from physics, and that econophysics was prepared to accept the modeling of social phenomena as legitimate—thus enlarging its scope and possible job market—brought econophysics under the wing of physics as it first grew by using existing physics journals for publication and physics departments as training ground for the new breed of "econophysicists" (Gingras et al. 2012). We are seeing the emergence of a veritable scientific community independent of financial economics with its own academic courses, its own symposiums, and journals that are recognized in the field of physics.

In Whitley's view, the lack of openness displayed by economics is designed to preserve the dominant theoretical framework and to marginalize anomalies that are likely to challenge the discipline: "as long as the theoretical establishment is able to dismiss 'anomalies' and difficulties as peripheral and the province of 'applied' subfields and yet retain control of the assessment of research competence in all areas, fundamental change seems improbable" (Whitley 1986a, p. 204). This closed attitude in economics considerably restricts the scope for econophysics to win over financial economists. Moreover, physics shares the same closed-mindedness: according to the *Science and Engineering Indicator*s (2000, p. 103, table 6–54), economics is the most hermetic field of the social sciences, with more than 87% of intra-disciplinary references compared to 50% in sociology. This is even more self-contained than physics, which cite physics journals in about 80% of their references. These data are consistent with Whitley's (1986b) characterization of economics as a "partitioned bureaucracy" with a strong control over its theoretical core. Consequently, econophysicists have developed a closed attitude about financial economics.

The Refusal of Econophysicists to Incorporate the Framework of Financial Economics

As we have explained, from a statistical point of view, econophysics makes it possible to generalize the models used by the proponents of financial economics. However, up to now, most econophysicists have rejected the framework of financial economics

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[67] Econophysicists consider that particles (individuals) do not interact equally with each other because interactions depend on the distance between the particles. Therefore, as a function of their positions in the system, particles will interact and create different structures (molecules, crystals, etc.). The system will then be self-evolving and complex. Because atoms do not think, econophysicists consider that "market components" (including traders, speculators, and hedgers) obey statistical properties. See Schinckus (2010a) for a presentation of the main differences between economics and econophysics.

because they consider it “too axiomatic and formal to deal with complex systems” (Challet, Marsili, et al. 2005, p. 14). Even some economists (Keen 2003, p. 110) claim that all the key concepts (utility, perfect rationality, perfect competition, etc.) used in financial economics are “nonsense.” They are unobservable terms without an empirical base. Indeed, despite the fact that experiments exist in economics (Holt and Davis 2005), all key concepts of economics cannot be directly confirmed because, according to econophysicists, these concepts result from apriorism. In this perspective, the key notions of economics are considered as “empirically flawed” (Keen 2003, p. 109). For instance, the existence of equilibrium, which is a keystone of financial economics, has no foundation for econophysicists. In econophysics, equilibrium is rather considered as a potential state of the system because “there is no empirical evidence for equilibrium” seen as a final state of the system (McCauley 2004, p. 6). For econophycisists, economic equilibrium appears as an *a priori* belief[68] that provides a “standardized approach and a standardized language in which to explain each conclusion” (Farmer and Geanakoplos 2009, p. 17).

From a purely econophysics perspective, the financial market, like physical bodies, moves through different “phases,” which likewise display chaotic or coherent states. The evolution of phases and phase changes are, therefore, represented by a trajectory in this space. In accordance with chaos theory, physicists observe that, if one waits long enough, systems of this type tend to move through states that are neighboring or comparable to those they have been through in the past. In phase-diagram terms, the system is said to tend towards what is known as a “strange attractor.” This strange attractor cannot be assimilated into an equilibrium in the strict meaning of the term; rather, it is a geometric zone through which the system passes regularly.[69] The concept of strange attractor, taken directly from chaos theory, neatly sums up the idea that econophysicists have of the concept of equilibrium—which, in general, is explicitly rejected. “There is no empirical proof of the existence of a stable equilibrium,” explains McCauley (2004, p. 6). In his view, the importance placed on this notion is more the result of an ideology or a belief than of an observation of reality (McCauley 2004, p. 295). He goes so far as to use the idea of non-equilibrium to distinguish finance theory from economics:

> Standard economic theory and standard finance theory have entirely different origins and show very little, if any, theoretical overlap. The former, with no empirical basis for its postulates, is based on idea of equilibrium, whereas finance theory is motivated by, and deals from the start with, empirical data and modeling via nonequilibrium stochastic dynamics. (McCauley 2004, p. 6)

Mandelbrot (2005, p. 143) adds:

> Let us return to fluctuations in finance; where do we see an economic equilibrium that is the equivalent of normal thermodynamic equilibrium? I quickly developed the feeling that the notion of economic equilibrium is devoid of content and that, to describe price variation, it will not be sufficient to modify benign chance by incorporating new details.

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[68] See Schinckus (2011a) for further information about the importance of equilibrium in econophysics.

[69] This term remains to be defined on the basis of the nature of the phenomenon under study.

McCauley (2004, p. 78) explains that the concept of equilibrium used in economics is of Newtonian inspiration (classical mechanics), whereas the idea of non-equilibrium owes more to the logics of statistical mechanics. From this point of view, investors are particles with complex and heterogeneous behavior, operating in a system (the market) whose macroscopic state can be characterized statistically (by Lévy laws) by a set of values (asset prices) that are transitory (non-equilibrium). "This low-level complexity (which is in a way microscopic) [at the individual level] can, under certain conditions, cause surprising and not disorderly effects at the macroscopic (collective) level" (Brandouy 2005, p. 122). This macroscopic perception of non-equilibrium as the sole explanation of the system's microscopic states is directly inspired by thermodynamic models[70] and not by economics. This difference between economics and physics is also highlighted by Ruelle (1991, p. 113), and suggests that the notion of non-equilibrium could prove highly useful for the study of certain economic phenomena. Ball (2006, p. 687) adds that "equilibrium is the heart of the dominant economics whereas most models taken from econophysics are explicitly based on the concept of nonequilibrium." The rejection of the theory and hypotheses of economics does not facilitate theoretical exchanges, and contributes to the absence of debate alluded to in our previous section. The studies put forward by econophysicists are not presented as improvements but rather as new models to replace current economic models purely and simply. Economists, for their part, prefer to remain aloof from this "methodological imperialism" by publishing no (or few) articles on econophysics (Gingras et al. 2012).

This rejection of the theoretical framework of financial economics leads econophysicists to discard the discipline's main concepts and theories, as McCauley points out: "Econophysicists are safer to ignore the lessons taught in standard economic texts (both micro-macro) than to learn the economists' production ideas and take them seriously" (2006, p. 608).

IV. CONCLUSION

In the 1960s, Mandelbrot (1963, 1965) and Fama (1965a) emphasized the leptokurticity of empirical distributions and proposed describing the empirical distribution with stable Lévy processes. Although these processes appeared to be adequate for the statistical description of financial distribution, they were not developed at that time because they have infinite variance, and financial economists did not have the statistical tools to allow them to describe empirical distributions with a stable Lévy framework.

Since then, financial economics has attempted to integrate Lévy processes into its modeling (Matacz 2000, Tankov 2004). However, these attempts were founded on non-stable Lévy processes. In the 1990s, new statistical tools were developed with the aim of creating stable Lévy processes with finite variance. Econophysical works are directly in line with these new statistical tools. That is the point explained in this article, which has also shown how the development of a new way of collecting data

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[70] That is, a dynamic equilibrium in perpetual modification. There have also been attempts to unify the concept of equilibrium in microeconomics and in thermodynamics—see Sousa and Domingos (2006) on this subject. Nevertheless, these analogies are purely "axiomatic and conceptual" (Sousa et al. 2006, p. 162). They have not, for the time being at least, led to the study of particular economic or financial phenomena.

(intraday) has favored the emergence of econophysics. In a sense, this new field can be seen as the result of the technological and theoretical evolution of finance. This evolution was initiated by the first attempts of financial economists, but also by the purely mathematical framework developed by Harrison and Pliska (1981), who proposed a non-economic model in finance. Harrison and Pliska, in fact, provided an entry point for a less economics-based evolution of modern finance. As a result, from a mathematical viewpoint, the models developed by econophysicists continue from where those developed by financial economists left off. In one respect, econophysics has benefited from standing outside financial economics: this position means that they are not subject to the constraints of the theoretical framework, giving them greater freedom to develop new mathematical tools. And yet, the evolution of financial economics suggests that econophysicists might successfully infiltrate financial economics and, consequently, become the next dominant approach in financial economics. Recent work by financial economists to integrate Lévy processes could build bridges between the two approaches. These attempts to integrate Lévy processes into the framework of financial economics are a challenge for that discipline.

This paper also shows how econophysics and financial economics have historical similarities in their emergence process. In the 1960s, chartists and fundamentalists were marginalized in academic circles by financial economists. Since the 1990s, financial economists have been challenged by econophysicists, who suggest that they can supplant them using the same arguments that they themselves used in the 1960s. In other words, econophysicists are suggesting that their assumptions, their theoretical framework, and their results could serve as a reference point, with the result that current mainstream financial economics will position itself in relation to them. This attempt to supplant the dominant approach by the new theoretical field, combined with the importance of statistical tools, indicates some historical similarities between the emergence of both fields.

However, despite these similarities, we have highlighted aspects in econophysics' theoretical framework, results, and hypotheses that are obstacles to its bid to become the mainstream approach in financial economics.

While econophysics is an important challenge for financial economics, we observe a major difference between financial economics in the 1960s and econophysics today. Financial economists took over the business schools by marginalizing rival groups. This is not the case with econophysicists, who do not seem to be able to marginalize the dominant approach in financial economics. Rather, they appear to be attempting to carve out a place for themselves inside modern financial theory. However, to strengthen this position, bridges still need to be built between financial economics and econophysics; but that is another story.

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