Towards a transdisciplinary econophysics

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Abstract

This paper deals with the disciplinary dimension of a very new field called econophysics and shows that despite the fact that econophysics is regularly described as an interdisciplinary approach, it is in fact a multidisciplinary field. Beyond this observation, we note that recent developments suggest that econophysics could evolve towards a more integrated field. We therefore propose a prospective approach by analyzing how this field could become transdisciplinary. In this article, we focus on financial work, and we show that a common scheme is attainable and we investigate the possibilities of a trandisciplinary econophysics which will make possible to revisit the theoretical foundations of financial economics and develop new models and theories better suited to the management of financial risks and financial markets.

The contribution of this article is twofold: on the one hand it clarifies the epistemological status of econophysics, and on the other, it studies the recent evolution of econophysics and shows how this field could evolve to become transdisciplinary.

Keywords: Econophysics, Financial Economics, Interdisciplinarity, Multidisciplinarity, Pluridisciplinarity, Transdisciplinarity.

I. Introduction

This paper deals with the disciplinary dimension of a very new field called econophysics. In this article, we will focus on finance, which is the major area studied by econophysicists. Econophysics, created outside economics by physicists from statistical physics, studies economic phenomena, and more specifically financial markets, using various models and concepts imported from condensed matter and statistical physics[1]. This recent approach is often presented as a field between physics and economics, and more particularly financial economics (Keen 2003, Gingras and Schinckus 2012). Multidisciplinarity, interdisciplinarity and transdisciplinarity refer to different levels of integration of several disciplines. Analyzing these types of integration, this article shows that despite the fact that econophysics is regularly described as an interdisciplinary approach, it is in fact a multidisciplinary field. Beyond this observation, we note that recent developments suggest that econophysics could evolve towards a more integrated field. Thus we have taken a prospective approach, analyzing ways in which the field could become transdisciplinary. From this perspective, we show that a common scheme is attainable and we investigate the possibilities of a transdisciplinary econophysics that deals with modern finance theory.

The contribution of this article is twofold: on the one hand it clarifies the epistemological status of econophysics, and on the other it studies the recent evolution of econophysics and shows how the field could evolve to become transdisciplinary for finance.

This article is divided into three parts. The first part briefly presents econophysics and its main links with economics. The second part analyzes the disciplinary dimension of econophysics and shows that econophysics is a multidisciplinary field. The third part analyzes what “trans-econophysics” would be.

II. Econophysics, a new field of research

For over a decade, a considerable number of physicists have been applying concepts from physics to study economic phenomena. The term “econophysics” is now generally used to describe this work. According to Kutner and Grech (2008), econophysics as a field of research dates back to 1991 when Mantegna published a paper about the use of stable Lévy processes in finance. However, Jovanovic and Schinckus (2013) trace the roots[2] of the basic ideas of econophysics in finance to Benoît Mandelbrot (1963, 1965), who saw an analogy between the evolution of financial markets and the phenomenon of turbulence[3]. Despite these and some papers on pure Lévy processes in finance written in the mid-1960s (Fama 1965, Samuelson 1965), this statistical approach was not pursued at that time, essentially because of its incompatibility with the theoretical framework used by economists (Jovanovic*, et al.* 2013)[4].

Econophysics, as a specific label and conceptual practice, was first coined by the physicist H. Eugene Stanley in 1996 in a paper published in *Physica A* (Stanley, Afanasyev*, et al.* 1996). As the name suggests, econophysics presents itself as a hybrid discipline which can be defined in methodological terms as “a quantitative approach using ideas, models, conceptual and computational methods of statistical physics”[5] applied to economic phenomena, and especially financial phenomena (Burda, Jurkiewicz*, et al.* 2003, 1). More precisely, econophysics is characterized by the application of models from statistical mechanics (which is a subfield of statistical physics) that use stable Lévy processes to financial markets.

From a methodological perspective, we can distinguish between two different methodologies used in this field: one strictly statistical, and one agent-based (Chakrabortia, Muni Tokea*, et al.* 2011a, 2011b, Schinckus 2011). While the first involves the study of statistical regularities observed in the economic time series which seem to be persistent across various time periods, the latter is founded on an agent-based method[6] of reproducing observed data in real economic systems. Agent-based econophysics and statistical econophysics have common foundations, since they describe socioeconomic systems as complex systems – the unavoidable result of bringing together numerous components in a non-simple manner. As suggested by some authors (Farmer and Foley 2009, Schinckus 2012), these two perspectives appear to be complementary, since statistical econophysics provides analytical tools to describe and characterize macro-statistical regularities in the evolution of complex systems, while agent-based modelling provides a framework for reproducing these statistical regularities by giving them micro-foundations. In this paper, we deal only with statistical econophysics applied to financial economics, because this specific area covers the vast majority of the topics studied by econophysicists (Gingras*, et al.* 2012). Moreover, this area can meet the axiomatic condition required to favour the development of a transdisciplinary perspective (as will be explained in the following section).

The influence of physics on financial economics is nothing new[7]. A number of writers have studied the “physical attraction” exerted by economists on physics (Mirowski 1989, Ingrao and Giorgio 1990, Schabas 1990). But as McCauley (2004) points out, in spite of these 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 physics to develop their own discipline, as has been seen repeatedly in the history of economics[8]. This time, it is physicists that are going beyond the boundaries of their discipline, studying various problems thrown up by social sciences in the light of their methods and models.

Using standard tools of statistical mechanics such as microscopic models, the Ising model or scaling laws, econophysicists attempt to explain how "emergence" appears at the macro-level of complex economic systems[9]. Epistemologically, econophysics is founded on a belief in the regularity of some general statistical properties that reappear across many and diverse phenomena[10] (McCauley 2004). These statistical regularities can be characterized by scaling laws that are considered to be at the heart of econophysics[11] – (Bouchaud 2002), Stanley and Gabaix (2008, 288). These scaling laws can take a variety of forms. According to most econophysicists (Mandelbrot and Hudson 2004, McCauley 2004) complex economic systems[12] obey a specific kind of regularity that can be characterized by power-law distributions of the form $P(X > x) = x^{-\alpha}$, where $p(x)$ is the probability of there being an event of magnitude x and the scaling exponent α is a constant whose value is set either by the empirically observed behaviour of the system, by a theory or by simulations. Power laws are not the prime distinguishing characteristic of econophysics, since they have been used in economics for several decades[13]. Moreover, there exists a specific literature in finance debating the value of the exponent α for the best power law describing the financial distributions. Econophysics' distinctive feature is its application of models based on these power laws which have been adapted for the study of turbulence, meaning that the exponent α lies between 0 and 2 (in order to associate the statistical stability with the fractality; see Mandelbrot, (1999)). In other words, the specificity of econophysics is the use of stable Lévy processes (with $\alpha<2$)[14] to describe financial distribution (the existing literature debating the value of the exponent never provides a model $0 < \alpha < 2$).

The development of this new field raises questions about its differences from and potential contribution to financial economics. What explains the fact that, while econophysicists have been able to set themselves up as an entirely freestanding academic field, they have little interaction with financial economists? How could physicists who seem to be rejecting some of the main features of financial economics (as well as modern finance theory) contribute to a better understanding of financial phenomena? How could econophysics contribute to financial economics? How might it be possible to develop knowledge common to financial economists and physicists? These questions relate to the disciplinary dimension of econophysics.

III. The disciplinary dimension of econophysics

In the specialized literature, econophysics is often described as an interdisciplinary field: "[econophysics is an] interdisciplinary research field applying methods of statistical physics to problems in economics and finance" (Săvoiu and Iorga–Simăn 2008, 33). Although the definition of econophysics varies from author to author, most econophysicists seem to share the idea that their approach is really an interdisciplinary field. For instance, Aste and Di Matteo have stated that "Econophysics is an interdisciplinary field which applies the methods of statistical physics, nonlinear dynamics, and network theory to macro-micro/economic modeling, to financial market analysis and social problems"

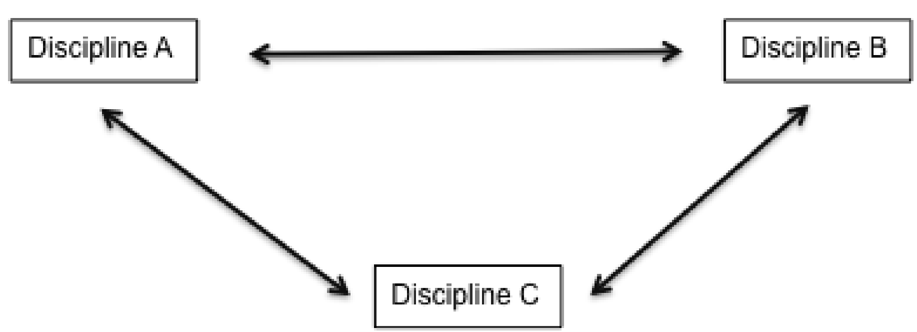
(2009, 3). Similar definitions can be found in the work of many authors, for example, Mantegna and Stanley (1999), Gligor and Ignat (2001), Vasconcelos (2004), Carbonne et al. (2007), and Daniel and Sornette (2010). However, in this part, after providing a general definition of the terms multi-, inter- and transdisciplinary, we demonstrate that this new field is a multidisciplinary one.

III.1. Multi-, inter-, and transdisciplinary

The association between disciplines is a relatively new phenomenon. As Max-Neef (2005, 6) emphasizes, this development "has been significant for the maintenance of disciplinary autonomy, for the competition of research funds and for the consolidation of academic prestige." While disciplinarity refers to a mono-discipline describing a specialized scientific field, notions such as multidisciplinarity (or pluridisciplinarity), interdisciplinarity, and transdisciplinarity imply a variety of disciplines. This section clarifies the concepts of multi-, inter-, trans-disciplinary, with the proviso that in this article we focus only on an epistemological perspective – see Max-Neef (2005) or Choi and Pak (2006) for a more sociological approach.

Multidisciplinarity implies several disciplines and provides knowledge that stays within the boundaries of the fields involved. More precisely, several disciplines are in association for the purpose of analyzing a common object with their own theories, models and concepts. Klein (1990, 110) explained that multidisciplinarity is "a process for providing a juxtaposition of disciplines that is additive, not integrative; the disciplinary perspectives are not changed, only contrasted." In other words, each field's knowledge provides a different perspective on a particular problem or issue. This kind of process "normally happens between compatible areas of knowledge" (Max-Neef 2005, 5) and, in a sense, a multidisciplinary project means research in which all experts take into account the different viewpoints involved.

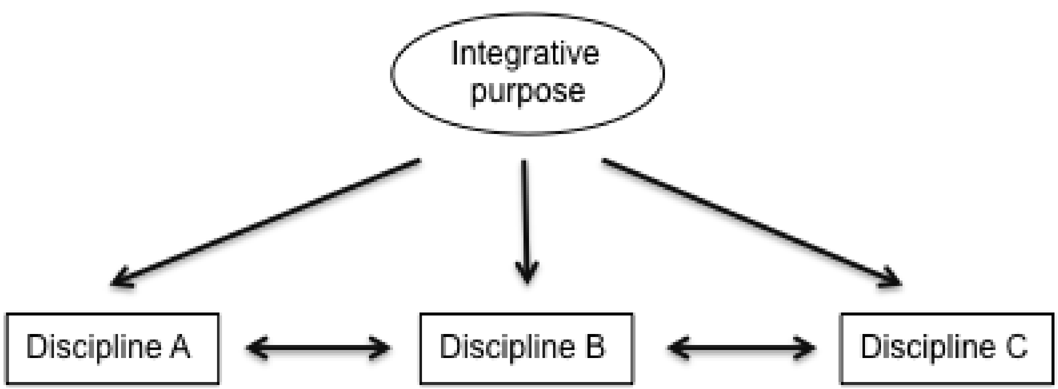
Multidisciplinarity (also called pluridisciplinarity)
(Cooperation without coordination)



Multidisciplinarity involves the use of a combination of disciplines in the study of a specific area of knowledge. The approach of each discipline contributes to a better understanding of the subject under study. The disciplines involved often cover compatible areas of knowledge, such as physics and chemistry, or sociology and politics. Among the many examples that could be cited are all phenomena related to heat, an understanding of which contributed to the development of the disciplines involved: physics and chemistry.

Interdisciplinarity is a very different approach because it refers to “joint, coordinated and continuously integrated research done by experts with a different disciplinary background, working together and producing joint reports and papers” (Grossman 1979, 54). An interdisciplinary team aspires to a more profound level of collaboration than a multidisciplinary team: “different backgrounds combining their knowledge mutually complete different levels of planned care” (Bernard-Bonnin, Stachenko*, et al.* 1995, 35). In this perspective, participants have common roles and they try to arrive at integration and synthesis of the disciplines involved by developing a common methodology, models and theories ((NSERC) 2004). Disciplinary knowledge, concepts and tools of investigation are considered and combined in such way that the resulting understanding is greater than the sum of its disciplinary parts. As Max-Neef (2005, 7) explained it, interdisciplinarity often has an integrative purpose:

Interdisciplinarity
(Cooperation and coordination)

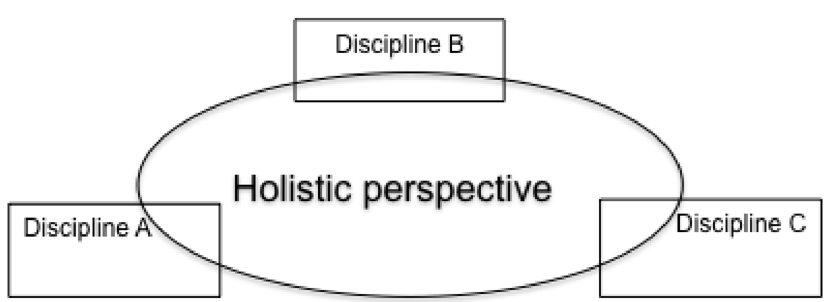


This integrative purpose can be pragmatic or normative. Medicine, for example, is based on empirical facts coming from biology, chemistry, psychology and even physics (for medical imagery). Medicine can thus be seen as an interdisciplinary field based on pragmatic purpose because all analyses involving several disciplines are focused on a pragmatic result (diagnosis or treatment). Engineering can also be considered as a pragmatic interdisciplinary field. Max-Neef (2005, 7) explained that politics, for example, is more of a normative interdisciplinary field since it indirectly touches on economics and sociology.

Transdisciplinarity describes the most integrative collaboration between disciplines. "Transdisciplinary projects are those in which researchers from different fields not only work closely together on a common problem over an extended period but also create a shared conceptual model of the problem that integrates and transcends each of their separate disciplinary perspectives" (Rosenfield 1992, 55). All participants then have common roles and try to offer a holistic scheme that subordinate disciplines. Transdisciplinary research is "concerned with the unity of intellectual frameworks beyond the disciplinary perspectives" (Stember 1998, 341). This kind of research involves issues in which each disciplinary knowledge involved takes into account the other disciplinary frameworks by adapting to them. The diversity of approaches and their different theoretical meanings make developing a common framework between two disciplines very difficult. On this point, Nicolescu (2010) explained that the first step in the development of a transdisciplinary methodology is encouraged if a metatheoretical isomorphism (i.e., a formal analogy) between the disciplines involved can be found, because this kind of isomorphism favours the emergence of a common axiomatic that would make sense for the disciplines involved (we will develop this point in the next section).

In a transdisciplinary perspective, disciplines must be looked on as necessarily complementary in order to better understand the complexity of reality. Rather than forming a new discipline or a supra-discipline, transdisciplinarity implies a more systemic and holistic way of thinking about the world[15]. The objective is to arrive at knowledge that transcends disciplines in order to create a common theoretical framework (i.e., a language that the involved groups can understand: we go into this point in detail in the next section). In other words, while multidisciplinarity and interdisciplinarity are merely continuous extensions of disciplinarity, transdisciplinary implies a unity that does not exclude the meaning "beyond disciplines" but reduces it through a specific interaction: "transdisciplinarity is both unified (in a sense of unification of different disciplinary approach) and diverse – unity in diversity and diversity through unity is inherent to transdisciplinarity (Nicolescu 2010, 23). We can represent transdisciplinarity as follows:

Transdisciplinarity
(Cooperation with integrative collaboration)



It is not so easy to find examples of trandisciplinary research because it implies a very integrative perspective. The ecology of today can be looked on as a transdisciplinary discipline. Max-Neef (2005) explained that *growth* and *environment* were frequently identified as opposites in conventional economics because they were mainly based on anthropocentric reasoning. By taking into account different fields (economics, demography, biophysics etc), a more biocentric ecology has been recently developed. This ecology has proposed a new framework in order to solve the traditional opposition between *environment* and *growth*. In this perspective, these opposite concepts can now be seen as complementary in a unified *development*. Rosser (2010, 6) explained that what we call "econobiology" could also be considered as a "transdisciplinary field based on a specific formalization of an evolving complex system common to economics and biology."

III.2. Econophysics: a multidisciplinary field

In this section, we will explore the disciplinary dimension of econophysics through published articles on finance.

Although econophysics and financial economics share the same topics (mainly the analysis of stock-price variations), they differ in the mathematics they use and the constraints they have to face. Econophysics' distinctive feature is the use of stable Lévy processes for modelling stock-price variations, while financial economics is based on (an improved) Gaussian framework (the last part will explain this difference in greater detail). Concerning constraints, econophysicists focus on the application of mathematical models to empirical data. They conform to rigid traditions of statistical mechanics treating social phenomena as conforming to "natural laws." In this perspective, the constraint they have concerning the fit between model and empirical data is very different from the constraints in economics. Indeed, financial economists have to face to a second constraint: the compatibility between models and the theoretical framework, which mainly comes from economics[16].

To be an interdisciplinary field, econophysics should provide an integration and a synthesis of economics and physics by developing a common methodology, models and theories. However, up to now, all models developed by econophysicists have stayed within the boundaries of statistical physics. Indeed, econophysicists try to explain economic phenomena only with theoretical tools, models and methods derived from physics. Chatterjee et al. explain:

> "The main force behind this outflow is not so much that physicists have lost interest in physics, but the realization that there are incredibly interesting complex phenomena taking place in other disciplines which seem now within the reach of the powerful theoretical tools which have been successful in physics" (Chatterjee, Yarlagadda*, et al.* 2005).

Econophysicists do not attempt to develop common models or theories by making a synthesis with models or theories from economics. In developing their own models, they apply concepts and models of physics as they exist today, ignoring financial economics' features. In other words, econophysics aims to provide a new perspective on stock-price variations – a traditional subject of financial economics – using tools and models from a specific disciplinary context: statistical mechanics.

Of course, scientific collaborations between financial economists and econophysicists exist –Foley and Farmer (2009) or Farmer and Lux (2008) for example. A special issue of the *Journal of Economic Dynamic and Control* dedicated to the "Application of Physics to Economics and Finance" was published in 2008, and some economists have provided a disciplinary reflection on econophysics (Keen 2003, Rosser 2008a, 2010). However, this kind of collaboration appears uneasy, and the work of these authors is multidisciplinary, since it attempts to find a mathematical analogy between financial economics and statistical mechanics but does not try to develop a framework common to both disciplines. Mathematical isomorphism is a necessary condition for the emergence of a transdisciplinary project, but it is not a sufficient condition. Basically, the existing collaborations between financial economists and econophysicists come up against two specific difficulties.

The first difficulty lies in the fact that most of the models used by econophysicists are not used by financial economists because they are incompatible with financial economics' theoretical framework. Jovanovic and Schinckus (2013) point out that Mandelbrot (1963, 1965) and Fama (1963, 1965) initiated a theoretical movement by using stable Lévy processes to describe financial markets. Fama (1965) also proposed a stable Lévy version of the portfolio theory. However, stable Lévy processes were soon put aside in financial economics because the variance of stable Lévy processes does not tend towards a fixed value: the variation is said to be *infinite*[17] (Jovanovic and Schinckus 2010b, 2013). The infinite-variance hypothesis is meaningless[18] in the framework of financial economics where variance and the expected mean are the two main variables for their theoretical interpretations. In the 1960s, the period in which financial economics was constituted as a scientific discipline, the relationship between risk and return was taken from Markowitz' work (1952, 1959). Markowitz associated risk with variance and return with the mean. Today, the whole of financial economics is built on this association. In this perspective, if variance were infinite (as it is in a stable Lévy process), it would be impossible to understand the notion of risk[19] as Markowitz had defined it and, consequently, as it is understood by financial economists. Physics models were thus incompatible with the key models (portfolio theory, CAPM, Black and Scholes model) framework of financial economics at the outset. This theoretical incompatibility contributes to confine econophysists and financial economists within their own intellectual ambit. It also goes some way towards explaining the difficult dialogue between the two fields (the last section will return to this point).

The second difficulty is the sociological response given by some econophysicists (McCauley, Gunaratne for example) who seem to be opposed to a potential collaboration with economists: they criticize financial economics by emphasizing, for instance, the "superficially appealing" nature of its concepts or by describing the field as a "tapestry of beliefs" (Keen 2003, 108)[20]. McCauley, one of the biggest names in econophysics, has stated that "econophysicists are safer to ignore the lessons taught in standard economics texts" (McCauley 2006, 602)[21]. This radical position is not shared by all econophysicists: in fact the majority have developed a number of (multidisciplinary) collaborations with economists (Gabaix, Parameswaran*, et al.* 2000, Farmer*, et al.* 2008, Farmer*, et al.* 2009). McCauley's position can be interpreted as the result of the difficult collaboration between the two communities: difficulty in collaborating leads each community to adopt a much more radical position towards the work of the other community[22]. Thus, these collaborations have not led to any change in the disciplinary perspectives. We merely observe the emergence of multidisciplinary-perspective projects attempting to show that a mathematical analogy is possible between the two disciplines. Today, despite these collaborations, econophysics remains an autonomous field (Jovanovic and Schinckus 2010a, Gingras*, et al.* 2012), and cannot be seen as an integrative and collaborative approach between econophysicists and financial economists. Because there is no integration or synthesis of physics and financial economics through the development of a common methodology, models and theories, we cannot consider econophysics as an interdisciplinary field, and thus not as a transdisciplinary field either.

Despite this conclusion, a remark from Rosser (2003, 1) is worthy of note: "Probably the most developed potentially transdisciplinary perspective on economic complexity is econophysics". Rosser (2010) rightly emphasized this potentialbut he did not explain in details how it could be achieved. Considering recent developments in this field, we are justified in asking whether a transdisciplinary econophysics in finance might be possible? Transdisciplinarity would provide an opportunity for creating fruitful interactions between the two fields. It would also enable financial economists and econophysicists to emerge from the confines of their own practice and intellectual ambit. In the next section, we will explore this question and the possibilities of such an evolution of the field.

IV. Towards a "transeconophysics" in finance

A transdisciplinary econophysics would imply a more integrative approach in which econophysicists and financial economists would share a common conceptual scheme that transcends both disciplines. This "integrative dimension" refers to two kinds of integration: on the one hand, a methodological integration to produce a common conceptual framework and, on the other hand, a sociological integration – meaning that theorists from the disciplines involved go beyond their cultural differences in order to work together in a common project.

The sociological integration is a matter of "inter-professionality" related to the standardization of knowledge "through the background" (D'Amour and Oandasan 2005) while the methodological integration refers to the knowledge itself. In this part, we focus on the methodological issue of the transdisciplinarity of econophysics[23] for analyzing a possible common scheme between econophysics and financial economics despite the current situation, and consequently the possibility for econophysics to become a transdisciplinary field.

IV.1. What transdisciplinary econophysics would be

As explained in part II, transdisciplinarity refers to knowledge that transcends disciplines in order to create a common conceptual scheme. Morin (1994) explains that "the big problem is to find the difficult path of the inter-relationship [*l'entre-articulation*] between sciences that have not only their own language, but basic concepts that cannot move from one language to another." Although a transdiciplinary project requires that disciplines share common features, and in particular a common conceptual scheme, the problem of language (concordances) must be also considered. Klein (1994) explains "A 'pidgin' is an interim tongue, based [on] partial agreement on the meaning of shared terms […]. Transdisciplinarity […] will begin with a pidgin, with interim agreement on basic concepts and their meanings." The concept of "pidgin" was introduced into the philosophy of science by Galison (1997), who called the Kuhnian incommensurability into question by explaining how people from different social groups can communicate[24]. From this perspective, a pidgin can be seen as a means of communication between two (or more) groups that do not have a shared language[25]. Galison (1997, 783) used the metaphor of "trading zone" (because in situations of trade, groups speak languages other than that of their home country) to characterize this process of communication between people who do not share the same language. More specifically, "two groups can agree on rules of exchange even if they ascribe utterly different significance to the objects being exchanged" (Galison 1997, 783). As Chrisman (1999) pointed out, the emergence of a pidgin requires specific conditions: regular contact between the language communities involved, the need to communicate between these communities and, lastly, the absence of a widespread inter-language.

The influence of physics in economics and finance is nothing new, and the increasing number of collaborations between physicists and economists shows that these two communities have been in direct contact for some time (Mirowski 1989, Schabas 1990) with a will to communicate with each other. As Farmer and Lux (2008, 6) wrote in the editorial of the special issue of the *Journal of Economic Dynamic and Control* dedicated to the application of physics to economics:

"We hope that this selection of papers offers an impression of the scope and breadth of the growing literature in the interface between economics/finance and physics, that it will help readers to get acquainted with these new approaches and that it will stimulate further collaborations between scientists of both disciplines" (see also Farmer and Foley (2009)).

In this respect, all the conditions seem to be met for the emergence of a new pidgin. Moreover, Jovanovic and Schinckus (2013) explained that econophysics was created because some theoretical continuities already existed between statistical physics and financial economics due to the fact that Gaussian processes are a particular case of Lévy processes. These continuities did not imply a common language, but they do encourage the potential emergence of a common conceptual scheme based on an axiomatic which would make sense for financial economists and econophysicists as well. In accordance with the analysis of Morin and Klein, a transdisciplinary econophysics must take into account the constraints that both original disciplines have to face: for econophysicists the need for statistical processes to be physically plausible (i.e., in line with the properties of physical systems[26]) and the fit between model and empirical data; for financial economists, the fit between model and empirical data on the one hand, and the compatibility between the model and theoretical framework on the other (see part III). Thus, this language implying a common conceptual scheme must result from a double movement: models from physics must incorporate the theoretical framework from financial economics and, at the same time, theories and concepts from financial economics must be modified so that they encompass richer models from physics.

This double movement is a necessary step towards a more integrative econophysics. Indeed, the creation of a transdisciplinary field requires each field involved to adapt in order to transcend each of their separate disciplinary perspectives. This adaptation implies the integration of theoretical constraints observed in each discipline in such a way that the new shared conceptual framework will make sense in each discipline. As Chrisman (1999, 5) has pointed out, the emergence of a pidgin can be seen as a new transdisciplinary jargon between two disciplines, as opposed to a multidisciplinary approach which implies what Chrisman called "boundary objects," which imply an agreement and an "awareness" between the groups involved through which each can understand that the other may not see things in the same way.

This double movement required for the emergence of a new pidgin can be seen in the evolution of econophysics. As we will explain in the next section, recent works suggest that a common framework between econophysicists and financial economists is possible, and consequently, a trans-econophysics seems conceivable.

IV.2. A trans-econophysics project in finance

IV.2.a) From Gaussian framework to exponentially truncated stable Lévy framework

Financial economists mainly use the Gaussian framework in order to characterize financial uncertainty. For econophysicists, the Gaussian framework is the first step of describing uncertainty in science. This first step can be generalized through an uncertainty “without normality” (Mandelbrot 1997, 66) based on the use of stable Lévy processes to describe complex phenomena. In this perspective, a condition for developing a theoretical bridge between econophysics and financial economics is a common framework in which the traditional Gaussian approach used in finance would make sense with the mathematical models used in econophysics.

The first step that could lead to the creation of transeconophysics in the area of finance has been taken with the use of truncated stable Lévy distribution, which made it possible to solve the infinite-variance problem. Indeed, this statistical solution opens the possibility of using stable Lévy processes to describe the evolution of financial prices[27], and consequently, the possibility of creating a common framework.

Truncating[28] a Lévy distribution consists in normalizing it using a particular function so that its variance is finite. In this perspective, stable Lévy distributions are used with the specific condition that there is a cut-off length for the price variations above which the distribution function is set to zero in the simplest case (Mariani and Liu 2007) or decreases exponentially (Gupta and Campanha 2002, Gunaratne and McCauley 2005). These functions are chosen in order to obtain the best fit with the empirical data (Mariani*, et al.* 2007) or are derived from models like percolation theory (Gupta*, et al.* 2002) or the generalized Focker Plank equation (Gunaratne and McCauley 2002). Generally speaking, the probability distribution of a truncated Lévy distribution can be defined as followed,

$$P(x) = \begin{cases} N(0,\sigma) & |x| > l \\ k\ L(x)_{(\alpha,\beta,\gamma,\delta)} & |x| \leq l \end{cases}$$

Where $L(x)_{(\alpha,\beta,\gamma,\delta)}$ is a symmetrical Lévy stable distribution with an index α ($0 < \alpha \leq 2$), a scale factor $\gamma > 0$ and $\beta = 0$ since the distribution is symmetrical. δ is a scale factor which is positive, *k* is a normalizing constant and *l* is the cut-off length. Usually, the standard Lévy distribution is abruptly cut to zero at a cut-off point (Mantegna and Stanley 1994). In other words, the probability of taking a step is abruptly cut to zero at a certain critical step size.

With truncated Lévy distribution, we can have finite variance, and can apply models that use this distribution to financial economics’ theoretical framework. This truncation of stable Lévy processes is a very important step towards a transdisciplinary econophysics because it allows the use of power laws (with $0 < \alpha < 2$) in financial economics and physics as well. Indeed, this development of truncated stable Lévy processes was the first step towards a more integrative econophysics in which the variance associated with risk in finance and with temperature must be finite. However, such processes are not fully compatible with the theoretical framework of financial economics as it exists today, and particularly since the publication of the articles of Harrison and Kreps and of Harrison and Pliska[29]. Indeed, truncated Lévy processes are not stable[30] and not infinitely divisible because the truncation of the distribution is abrupt[31]. The not-infinite-divisibility of truncated Lévy processes implies that they are not continuous processes, meaning that they cannot be applied in situations of complete markets (Naik and Lee 1990). The theoretical link between completeness of market and continuous processes was developed by Harrison and Kreps (1979) and Harrison and Pliska (1981). The completeness of markets has important consequences since it allows the possibility of having a unique price for contingent claims (like options). The incompleteness of markets implies a non-unique probability measure and therefore stochastic price processes take the form of a martingale, thus requiring a mathematical condition related to the existence of an arbitrage free market. Moreover, this abrupt truncation also generates debates in physics since some physicists (Gupta*, et al.* 2002) have claimed that an abrupt truncation is useful for very specific cases only, and that this methodology is insufficiently plausible in physics, because physical systems rarely change abruptly. Physicists therefore had good reason to go beyond abrupt truncated stable Lévy processes.

Consequently, a transeconophysics would require the use of continuous truncated stable Lévy distributions (implying therefore the uniqueness of prices, in line with a fundamental of financial economics[32] and in line with properties observed in the physical systems). Some authors, from both econophysics (Mantegna 1991, Koponen 1995, Gupta and Campanha 1999) and economics (Lux 1996, Gabaix*, et al.* 2000) have worked on the development of exponentially truncated Lévy processes. These would allow the emergence of a transeconophysics because, unlike truncated Lévy processes, they are continuous processes[33]

Exponentially truncated stable Lévy distributions were introduced in physics by Koponen (1995). In the truncated stable Lévy process, the cut-off is a decreasing exponential function. Gupta and Campanha (1999) generalized this approach in econophysics by the following probability distribution,

$$P(x)=\begin{cases} L(x)_{(\alpha,\beta,\gamma,\delta)} & |x|>l \\ e^{-f(t,l)}\ L(x)_{(\alpha,\beta,\gamma,\delta)} & |x|\le l \end{cases}$$

where l is the cut-off at which the distribution begins to deviate from Lévy distribution. $e^{-f(t,l)}$ is a decreasing function depending on time (t) and the cut-off parameter(s) (l) Like abruptly truncated Lévy distributions, exponentially truncated Lévy distributions have finite variance but their advantage is that they are infinitely divisible, and therefore potentially allow creation of a common theoretical framework based on uniqueness of the financial prices. Because exponentially truncated stable Lévy processes can be compatible with fundamentals of physics (no infinite variance, implying an infinite temperature, no abrupt truncation) and of finance (no infinite variance implying an infinite risk and continuity) as well, this specific statistical process could therefore favour the emergence of a common axiomatic between the two disciplines.

IV.2.b) Towards a financial economic interpretation of mathematical models coming from econophysics

The theoretical generalization of the statistical framework used by financial economists is an important step in a more integrative econophysics. However, a transeconophysics would need to develop an economic meaning for this generalization. From this perspective, Lévy processes and their parameters must have economic implications that will provide a common framework. Surprisingly, work on this issue does not even exist in econophysics. In the rest of this section we show that financial concepts of risk can be reinterpreted in such a way that they can fit into the framework suggested by stable Lévy processes.

The general form of Lévy distributions $S_{\alpha,\beta}$ (γ, δ) can be characterized by four parameters corresponding to the four first moments of the distribution. Depending on the value of these four parameters, two categories of Lévy processes can be identified: stable and non-stable. As we mentioned, econophysicists mainly use stable Lévy processes. A random variable X is said to be α-stable if we have specific values for parameters (α, β, γ, δ) such as $0 < \alpha \leq 2$, $\gamma \geq 0$, $-1 \leq \beta \leq 1$, $\gamma \in \Re$. All the usual stable distributions (Gaussian, Cauchy, Poisson, etc.) can then be found depending on the value of each parameter (α, β, γ, δ). Financial economics focuses on the mean (which characterizes return) and the variance (which characterizes risk). This discipline usually defines market risk as the dispersion of unexpected outcomes due to financial-market movements. From a statistical point of view, this dispersion is the result of the volatility and then the variance of the financial distributions. We consider that stable Lévy processes make it possible to complete the definition of traditional financial risk (volatility). Several papers are devoted to the analysis of these statistical parameters, but focus on variance or skewness only. In this perspective, we will propose to interpret each of the four parameters in terms of financial economics' theoretical framework, and more precisely, in terms of financial risk.

The *parameter* α is called the "characteristic exponent" and it shows the index of stability of the distribution. This value of this exponent determines the shape of the distribution: the lower this exponent, the fatter the tails (extreme events then have a higher probability of occurring). In other words, the lower α is, the more often extreme events are observed. In financial terms, then, this parameter is an indicator of risk since it describes how often important variations can occur. More precisely, α makes it possible to decompose the risk of a process into a "risk of shape." This risk is often neglected[34] because it is often associated with traditional Gaussian distributions[35].

The *parameter* γ is the scale indicator, which can be any positive number. It indicates the "random size," i.e. the size of the variance whose regularity is given by the exponent α. This parameter describes the size of the variations (whose regularity is given by α). In a sense, γ can be seen as an indicator of statistical dispersion because it provides information about the potential maximum loss. It allows the risk of a process to be decomposed into a "size risk". This risk is well known to financial economists, since this statistical dispersion is supposed to be reduced through diversification.

The two last statistical parameters, skeweness and localization factor, have been the focus of greater study in the financial literature.

The *parameter* β is an index of skewness: it gives information about the symmetry of the distribution and then about the place on the distribution where the most extreme value can be found. If $\beta = 0$, the distribution is symmetric. If $\beta < 0$ it is skewed toward the left (totally asymmetric toward the left if $\beta = -1$) meaning that most values are concentrated on the left of the distribution but that the most extreme values are on the right. When $\beta > 0$ indicates a distribution skewed toward the right (totally asymmetric toward the left if $\beta = -1$), with most values concentrated on the right but the most extreme values on the left of the statistical distribution. This parameter is already well known in financial economics, since many works are devoted to the analysis of the skewness of financial distributions (see, for example, Rubinstein (1973), Sears and Wei (1985) or Harvey and Siddique (2000)).

Finally, the *parameter* δ a localization factor: it shifts the distribution right if $\delta > 0$ and left if $\delta < 0$. This factor describes the concentration of the data. It could be the mean of the median or other parameters that could describe the general shape of the distribution. This factor is not really a measure of risk since it describes what are the more frequently observed data. In this perspective, δ is rather a descriptive feature of the distribution.

Conclusion

This paper has dealt with the disciplinary dimension of econophysics. Analyzing the disciplinary dimension of this field helps to explain why interaction and collaboration between economics and econophysics is still weak even though this “new” field is more than 20 years old. In this article, we have focused on finance because most articles in econophysics deal with this topic. However, the trend to bridge economics/finance and econophysics can be extended to other parts of economics. Bak, Paczuski and Shubik (1997), for example, dealt with the stochastic nature of the emergence of certain goods as a means of common exchange between all agents (i.e., how these goods become money). They emphasized that this emergence of money is a history- (time-) dependent process. Donangelo and Sneppen (2000) and Shinohara and Gunji (2001) studied the dynamics of exchange in a system composed of many interacting agents until an emergence of money occurs. They show how this process can be described through a scaling relation between the number of exchanges and time. While Donangelo and Sneppen (2000) used non-Gaussian statistics where fluctuations of exchanges are quantified by the anomalous Hurst exponent[36] (i.e., scaling laws); Shinohara and Gunji (2001) developed a reciprocity model in which the interactions between agents is asynchronous[37] and the duration of the good M (i.e., the time needed by M to become money) follows a power law (Shinohara*, et al.* 2001, 146). The theoretical bridge we evoked in this article could also be extended to non-economic fields: Artemi (2009) has worked on the potential contributions of econophysics to political decision making while Shi and al. (2010) have emphasized possible collaborations between econophysicists and psychological biases influencing the decision making process. This paper has focused only on the bridge between financial economics and econophysics, but while econophysicists mainly deal with financial markets, all the works mentioned above show that the potential transdisciplinarity of econophysics could concern several subfields of economics.

We first showed that econophysics is a multidisciplinary field (rather than an interdisciplinary as several authors often claim). This result helps to explain that econophysics and financial economics stay within the confines of their own discipline and their own habits.

We then posited the possibility of a transdisciplinary field between financial economics and econophysics. We show that the emergence of a transeconophysics is possible through a common framework that would result, on the one hand, from the adaptation of statistical physics models to theoretical constraints observed in financial economics and in physics as well. Combining the increasing number of collaborations between financial economists and econophysicists, the development of exponentially truncated stable Lévy processes is the first condition for a transdisciplinary econophysics in finance. In the last section, we completed this first condition by providing an economic meaning to the statistical parameters defining these stable Lévy processes. .

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[1] On the history of econophysics see Jovanovic and Schinckus (2013), Roehner (2002) or Daniel and Sornette (2010).

[2] The leptokurticity of financial distribution is a very old issue (Mitchell for example, recognized the presence of kurtosis in financial return in 1915). Likewise in economics, a specific case of this statistical framework (Paretian law) had been used before Mandelbrot's work (for example, by Pareto, who pioneered the use of power law distributions even prior to their use in physics). However, Jovanovic and Schinckus (2013) explained why the application of models taken from statistical mechanics (stable Lévy processes) to financial economics were not used in finance before the 1960s.

For further details about the use of power laws in economics and social sciences, see also Plerou *et al.* (2000).

More specifically, Mandelbrot's stable Lévy processes and their fractality, thanks to the statistical stability of these processes, were used to characterize the phenomenon of turbulence. Mandelbrot showed that it was possible to find a complex regularity (fractality) through statistical stability. In this regard, stable Lévy processes produced a statistical interpretation of his fractal geometry (Mandelbrot 1999). See Mirowski (1990) for further details about the analogy of financial markets with fractal geometry.

[4] The basic incompatibility stems from the indeterminacy of variance in Lévy processes. From a financial perspective, this would imply indeterminacy of the measurement of risk. We evoke this point in the last part of this article.

[5] The first definition of econophysics given by Stanley was more sociological: he wrote that econophysics is "a multidisciplinary field… that denotes the activities of physicists who are working on economic problems to test a variety of new conceptual approaches from the physical sciences" (Mantegna and Stanley 2000, viii-ix). However, this sociological definition generates an epistemological contradiction: if econophysics involves the activity of physicists only, it cannot be a multidisciplinary field, because that would require a minimum of collaboration between specialists from different disciplinary contexts, implying therefore that other theoreticians can also do econophysics. If physics can legitimately be considered as the purview of physicists, why should econophysics be seen as a "reserved area" for physicists? The rest of this paper will explore such questions.

[6] Agent-based modelling is based on computerized simulations of a large number of decision-makers that can interact through specified procedures. The agent-based approach appeared in the 1990s as a new tool for empirical research in a number of fields: economics (Axtell 1999), voting behavior (Lindgren and Nordahl 1994), military tactics (Ilachinski 2000), organizational behaviour (Prietula, Carley*, et al.* 1998), epidemics (Epstein and Axtell 1996), traffic congestion patterns (Nagel and Rasmussen 1994), etc.

[7] One of the first authors to bring physics closer to the financial domain was Jules Regnault in the second half of the 19th century (Jovanovic and Le Gall 2001, Jovanovic 2006). In the 20th century, a number of physics concepts played a part in the development of modern financial theory. The best known application of physics to finance is the application of the heat-diffusion formula (Bachelier, Black and Scholes) and a number of studies implicitly or explicitly referred to a concept from the field of physics: Brownian motion (Jovanovic 2009).

[8] Of course, there are physicists doing economics and economists with advanced degrees in physics, but these theoreticians always try to give an economic meaning to their importation of concepts from physics. The specificity of econophysics lies in an absence of economic meaning: econophysicists consider economic systems simply as physical systems, with no transfer of economic meaning to the final results.

[9] Some authors (McCauley 2004, Israel 2005) argue that the idea of "emergence" is empty and should be replaced by the physics-based concept of invariance, Rosser (2008b) showed that the distinction between the two is irrelevant and results from the old methodological struggle between the continuous and the discrete. See Rosser (2008b) for a very good introduction to this point.

[10] Some econophysicists (McCauley, for example) attribute an ontological nature to these regularities since they consider them a kind of "universality" (see Rickless, 2007 for an analysis of universal law in econophysics).

[11] These scaling laws can then be viewed as a macro result of the behaviour of a large number of interacting components from lower levels. As Rickles (2007, 7) explains, "The idea is that in statistical physics, systems that consist of a large number of interacting parts often are found to obey 'universal laws' - laws independent causally of microscopic details and dependent on just a few macroscopic parameters".

[12] Even if power law distributions are also used to characterize many phenomena in social sciences (such the ranking of firm size (Stanley*, et al.* 1996); the income distribution of companies (Okuyama, Takayasu*, et al.* 1999); fluctuations in finance (Mandelbrot 1997), these laws are often replaced by log-normal laws in which the variance parameter is not infinite.

[13] Pareto, in his *Cours d'Economie Politique* (1897) was the first to investigate the statistical character of the wealth of individuals by modelling them using power laws.

[14] If $\alpha > 2$, then the Lévy process is no longer stable.

[15] As Nicolesu (2010, 22) pointed out, "there is no opposition between disciplinarity (including inter-multi disciplinarity) and transdisciplinarity but there is instead a fertile complementarity, In fact, there is no transdisciplinarity without disciplinarity".

[16] See Jovanovic (2010) for an illustration with efficient market theory.

[17] The adjective "indeterminate" would be more accurately employed, but the literature uses "infinite".

[18] Of course, financial economists know that financial distributions are not empirically Gaussian. Therefore, they have developed a large variety of statistical processes to better understand the dynamics of financial markets. However, all these statistical solutions imply either a Gaussian world (with continuity where an optimal hedging is possible and therefore in line with the theoretical framework defined by Harrisson, Kreps and Pliska) or a non-Gaussian framework (discontinuous pump processes) in which a perfect riskless hedge is not plausible (and therefore in opposition to the dominant axiomatics defined by Harrisson, Kreps and Pliska). Work in the first category falls into what we call the ARCH types models, which remain implicitly based on a Gaussian framework since they consider that unconditional distributions are governed by Gaussian processes (whose tails can be fatter and then explained in terms of conditional distribution). In other words, these models provide a statistical description (which can be non-Gaussian) of the variance observed in unconditional distribution. As mentioned above, work in the second category involves jump processes, which are based on a discontinuous process describing the financial distribution – implying that a perfect hedging strategy is inconceivable. Moreover, the large number of statistical processes used in this specific literature does not favour the crystallization of a unified financial theory. (For further information about this distinction, see Rachev et al. (2011) or Schinckus (2012)).

[19] Of course, there exist some measures of risk that are not based on variance (Markowitz 1959, Fama and Roll 1971). Moreover, it is worth mentioning that the association of risk with variance implies a specific dependence between random variables which is not invariant under non-linear, strictly increasing transformation. However, asset prices are a strictly increasing function of return, but the correlation structure is not maintained by this kind of transformation, meaning that returns could be uncorrelated whereas prices are strongly correlated and vice-versa. Use of a specific function called *copula* is then in order to characterize this particular dependency between random variables. See Embrecht (2009) for further information.

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

[21] McCauley (2006, 17) did not hesitate to compare financial theory to cartoons: "the multitude of graphs presented without are not better than cartoons because they are not based on real empirical data only on falsified neoclassical expectations."

[22] A survey we conducted supports this interpretation: econophysicists' manuscripts are often rejected by economic journals because their empirical approach is different from that of economists.

[23] See Gingras and Schinckus (2012) for a more sociological analysis of the emergence of econophysics.

[24] Galison (1997) explained how engineers collaborated with physicists in order to develop particle detectors and radar.

[25] The Creole language is often presented as an example of a pidgin because it results from a mix of regional languages (Chavacano from the Philippines, Krio from Sierra Leone and Tok from Papua New Guinea); see Todd (1990).

[26] What philosophers of science call the "physical claim" of models used in physics (Barberousse, Franceschelli, *et al.* 2009). See also Schinckus (2011) for further information about how econophysicists made stable Lévy processes physically plausible.

[27] Note that truncated stable Lévy processes can be seen as the statistical solution to the problem of infinite variance emphasized by Mandelbrot (1963) and Fama (1965).

[28] Truncation is a specific calibration of statistical distribution which must not be confused with a linear transformation of distribution – for example, the use of log-normality.

[29] It was Harrison and Kreps (1979), Harrison and Pliska (1981), and Kreps (1981) gave a rigorous mathematical framework to definitions, hypotheses and results that constitute the heart of modern financial theory.

[30] Only non-truncated Lévy processes are stable (Mandelbrot 1963).

[31] This implies that its shape is changing at different time horizons and that distribution at different time horizons do not obey scaling relations. Indeed, the variable x progressively converges towards a Lévy distribution for $x < N^*$ while it converges toward to a Normal distribution when x is beyond the crossover value N^*. More precisely, scaling turns out to be approximate and valid for

a finite time interval only. For longer time intervals, scaling must break down. Moreover, some physicists have claimed that an abrupt truncation is only useful for very specific cases, but that this methodology would not be sufficiently physically plausible.

[32] Stable Lévy processes are a specific case of pure-jump processes and, as noted earlier, it is generally accepted that a pure-jump process corresponds to an incomplete market (Nolan 2009). However, a stable Lévy framework is not a strictly compound jump-process. Carr and Wu (2003, 754) explained that "in contrast to a standard Poisson or compound Poisson process, this pure jump process [stable Lévy process] has an infinite number of jumps over any time interval, allowing it to capture the extreme activity traditionally handled by diffusion processes. Most of the jumps are small and may be regarded as approximating the transition from one decimalized price to another one nearby". In this perspective, stable Lévy processes can be seen as quasi-continuous processes, as emphasized by Nolan (2009).

[33] They approach the continuous limit, being composed of an infinite number of small jumps in each time interval. This feature would make it possible to link these processes with research into the uniqueness of option prices.

[34] Even when financial economists use models derived from ARCH (EGARCH, GARCH, etc.) to capture the leptokurticity of financial distributions, they implicitly assume that these distributions are Gaussian. Moreover, although, the standard ARCH model used in finance can reproduce the power-law distribution of returns, they assume finite memory on past events and hence they are not consistent with long-range correlations in volatility observed on the market. It is worth mentioning that some authors have recommended the development of non-Gaussian alternatives, which would be based on complex heuristics, providing rules of thumb to practitioners (Haug and Taleb 2011).

[35] Financial economists usually use the concept of kurtosis to describe the leptokurticity of a distribution. However, this statistical concept is a Gaussian parameter (Balanda and MacGillivray 1988) and it often underestimates the leptokurticity in comparison with observed results (Tankov 2004).

[36] The Hurst exponent is the scaling property of the fractal Brownian movement. This statistical parameter is generally used to describe the time-dependent phenomenon.

[37] Each exchange needs a reciprocal situation and has a particular duration.