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THE INSTITUTIONALIZATION OF ECONOPHYSICS IN THE SHADOW OF PHYSICS

BY

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Econophysics presents itself as a new paradigm and a new specialty (or even a discipline) using various models and concepts imported from condensed matter and statistical physics to analyze economic and financial phenomena. Given that econophysics is based on different fundamental assumptions from those of mainstream economics, the disciplinary position of econophysics is not so clear. In this perspective, this paper will analyze the progressive institutionalization of econophysics using bibliometric methods to identify core authors as well as the structure of the disciplines with which econophysics is closely related.

I. INTRODUCTION

Econophysics presents itself as a new paradigm and a new specialty (or even a discipline) using various models and concepts imported from condensed matter and statistical physics to analyze economic and financial phenomena. As we will see, it grew rapidly in the second half of the 1990s, and generated several methodological debates (Lux and M. Ausloos 2002; Rickles 2007; Rosser 2007; Gallegati et al. 2006). A striking characteristic of econophysics is the fact that most papers on this subject have not been published in the mainstream economic or financial journals but in well-established physics journals such as *Physica A* and *Physical Review E*, usually devoted to topics related to condensed matter and statistical mechanics. This single fact already poses a series of related questions: 1) what exactly are the relations

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between econophysics and mainstream economics and finance? 2) why do economists seem to have resisted the presence of econophysics papers in their major journals? and 3) why have physics journals opened their doors to objects apparently so far from the usual inanimate objects of physics, involving as they do the collective behavior of humans instead of the collective interactions between atoms?

In order to contribute to answering, at least partly, these questions, this paper will analyze the progressive institutionalization of econophysics using bibliometric methods to identify core authors as well as the structure of the disciplines with which econophysics is closely related. Thus, we will be in a position to map the relations between econophysics and economics, and to measure the relative autarchy, up to now, of econophysics vis-à-vis economics and finance, as a research field. Since the name "econophysics" has been coined in 1996, our analysis is based on a sample of key papers divided into two periods, 1980 to 1995 and 1996 to 2008, in order to analyze the emergence of the field before its official recognition through that very act of naming it. In addition to this quantitative characterization of the field, we will show how it became institutionalized over the last decade by creating the usual tools of a discipline; namely, conferences, textbooks, journals, and even training programs leading to PhDs in econophysics. As we will see, in addition to being separate from economics in terms of place of publication and training, econophysics also uses specific concepts and tools that give this research field its unity and distinguish it from mainstream economics and finance.

Though many papers (Kutner and Rech 2008; De Liso and Filtatrella 2002; Savoiu and Siman 2007; Yegorov 2007) already recognize the growing importance of econophysics in the academic sphere, none have, to our knowledge, studied the process of institutionalization of that research field, and analyzed in a quantitative manner the position of that field among the space of scientific disciplines and specialties. As we conceive it, institutionalization can be understood as comprised of several phases. The first is, of course, the emergence of a new research practice based on a novel idea or technique, here the application of statistical physics methods to economic phenomena. But in order to endure over time, a new approach also requires discussion and publication venues as well as training programs in order to reproduce its research domain when that can not be done in already existing institutions and programs.[1] As we will see, this is what happened to econophysics, which did not develop as a specialty inside the dominant field of economics but, rather, outside it by finding a niche in the existing institutions of the physics discipline. However, economics hardly can be indifferent to the emergence of econophysics because this new field aims at offering explanations about the economic reality, the very object of the economic discipline.[2] Since models coming from econophysics pretend to offer better predictions, they do challenge the dominant economic models.[3]

[1]For more details on this model of institutionalization of scientific disciplines, see Gingras (1991) and Bourdieu (2004, pp. 47–51).

[2]For further information about the potential contributions of econophysics to economics, see Schinckus (2010a).

[3]See Artemi (2009) for reflections on the potential contributions of econophysics to political decision making.

II. THE EMERGENCE OF ECONOPHYSICS AS A RESEARCH FIELD

According to Kutner and Grech (2008), econophysics as a field of research dates back to 1991, when Mantegna published a paper about Lévy processes in finance. However, Jovanovic and Schinckus (2010a) trace the roots of the basic ideas of econophysics to papers by Benoît Mandelbrot (1963, 1965), who saw an analogy between the evolution of financial markets and the phenomenon of turbulence. In the 1960s, Samuelson (1965) evoked the possibility of using Lévy processes in finance but the first authors to make use of these processes in finance were Mandelbrot (1962, 1963, 1965) and especially Fama (1963, 1965), who tried to study financial markets using a non-Gaussian statistical framework directly inspired by Lévy's work (1924) on the stability of probability distributions,[4] and the generalization of the central-limit theorem proposed by Gnedenko and Kolmogorov (1954).[5] According to these works, Lévy processes, in their Paretian form, provide a better description of the evolution of financial markets, and they take into account price variations that are very large in relation to average variations, allowing, therefore, the possibility of price "jumps." However, the stability of the Paretian distribution means that the variance depends on the size of the sample and the observation scale, and does not tend towards a limit value. The variation is said, therefore, to be *infinite* because it does not have a limit-value.[6] This infinite variance appears to be the cause of the abandonment of Lévy processes in financial economics (see Jovanovic and Schinckus 2010a).

The infinite variance hypothesis was unacceptable because it is meaningless in the framework of financial economics. Variance and the expected mean are the two main variables of theoretical significance. 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. In this perspective, if variance were infinite (as it is in a Lévy process), it became impossible to understand and to compute the notion of risk as defined by Markowitz.

[4]In the 1920s, the famous French statistician Paul Lévy carried out work on the stability of probability distributions. In this context, stability means that any linear combination performed on a probability distribution characterized by a particular statistical law will generate a new probability distribution in accordance with the same statistical law. Lévy demonstrated that this invariance of the distribution form under the addition of independent variables was not specific to Gaussian distribution. It was precisely this characteristic of statistical invariance put forward by Lévy that enabled Mandelbrot to extend his fractal geometry (which itself was based on an invariance characteristic) to the study of statistical phenomena. Lévy's work leading to the identification of α-stable laws appeared, from that moment on, as a generalization of the Gaussian statistical framework. As Schoutens (2003) made clear, the family of α-stable distributions appears to be a general form of a number of known statistical laws such as normal distribution, Cauchy's law, Pareto's law, and Lévy's law. For a statistical presentation of these specific laws, see Schoutens (2003).

[5]In accordance with this generalization, the sum of random variables according to Lévy's laws, distributed independently and identically, converge towards a stable Lévy law having the same parameters. This generalization of the central-limit theorem is important because it represents a justification and a strong statistical foundation for the use of Lévy's laws to characterize complex phenomena.

[6]The adjective "indeterminate" would be more accurate, but the literature uses "infinite."

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The use of Lévy in finance, then, has been progressively abandoned, and this point has not been discussed in the literature, since it implied a new measure of risk (Fama 1965). Ten years after his 1965 article, Fama (1976) himself preferred to use normal distribution to describe monthly variations, thereby abandoning α-stable distributions. In his extension of modern portfolio theory to the Paretian framework, Fama (1965, p. 416) deplored the fact that no computational definition yet existed for evaluating this parameter. This led him to conclude: "Although the model discussed in the previous sections provides a complete theoretical structure for a portfolio model in a stable Paretian market, there are several difficulties involved in applying the model in practical situations" (Fama 1965, p. 414).

Although "[a]t the moment [1963] very little is known about the sampling behavior of procedures for estimating the parameters of these distributions," Fama (1963, p. 429) explained that the next step in the acceptability of Levy processes in economics would be "to develop more adequate statistical tools for dealing with stable Paretian distributions" (1963, p. 429).

It was only about thirty years later that these discussions re-emerged under the label "econophysics." As a specific label defining a conceptual practice, it was first coined by the physicist H. Eugene Stanley in 1996 in a paper published in *Physica A* (Stanley et al. 1996) As the name suggests, econophysics presents itself as a hybrid discipline that can be defined in methodological terms as "a quantitative approach using ideas, models, conceptual and computational methods of statistical physics" applied to economic and financial phenomena (Burda, Jurkiewicz, and Nowak 2003, p. 1). A similar definition of econophysics is found in Mantegna and Stanley (2000, p. 355).

Econophysics presents itself as a new way of thinking about the economic and financial systems through the "lenses" of physics. As much as neoclassical economics imported models from classical physics as formulated by Lagrange (Mirowski 1989), and financial economics built on the model of Brownian motion also imported from physics, so too econophysics tries to model economic phenomena using analogies taken from modern condensed matter physics and its associated mathematical tools and concepts. And, whereas mainstream microeconomics is based on the rational behavior of individuals, econophysics focuses on interactions between actors that lead to the emergence of statistical macro-laws, which are typically power laws instead of Gaussian ones as expected in neoclassical economics.[7] This approach is directly in line with the development of so-called "complexity science" during the 1990s (Rickles 2007), for which economic systems are obvious candidates for a treatment in terms of "complexity" because they are composed of multiple components (agents) interacting in such a way as to generate the macro-properties of economic systems and subsystems (Rickles 2008, p. 4).

Though economists and econophysists have in common their focus on mathematical modeling, there is a deep difference in the way they model economic behaviour. Economics tends to be based on methodological individualism and focused on individuals' characteristics, analyzing their behaviour in terms of given personal

[7]Let us mention that Gaussian law is a specific case of the power law used in econophysics. However, econophysicists explicitly reject the notion of representative agent because the knowledge they develop is macro-founded. For more details on this point, see Colander et al. (2008), and Schinckus (2009a, 2010).

elements (utility function, risk aversion, etc.). Beyond that, all psychological and emotional factors are excluded from the economic analysis, the mainstream being based on the notion of perfectly rational agents (Mongin 2002; Lallement 2000), a notion that supposes a specific modeling of individual behavior. In neoclassical economics, rationality explains the (microscopic) behavior of each individual[8] without taking into account the result of their interactions with the economic system.[9]

In opposition to this view, econophysics provides no specific model of the rational individual's behavior. Econophysicists avoid the difficult task of theorizing about the individual psychology of investors (Brandouy 2005), and they do not care about rational agent theory. In that sense, there is no real micro-econophysics, and that discipline does not take into account the personal characteristics (utility, etc.) of individuals. Econophysicists do not focus on the interactive abilities of agents but, rather, on the macro-result of their interactions. Financial systems consist, then, of a large number of components whose interactions generate observable properties. The heterogeneity of the components (agents) is supposed to be captured in the macro-result of the system. Few works in econophysics are dedicated to the analysis of the heterogeneity and interaction of agents, which is an approach that refers to a larger field including experimental psychology and artificial intelligence.

Using the standard tools of statistical mechanics, such as microscopic models, the Ising model, and scaling laws, econophysicists aim at explaining how emergence[10] appears at the macro-level of complex economic systems. Epistemologically, econophysics is founded on the belief in the universality of some general statistical properties that reappear across many and diverse phenomena (McCauley 2004). This statistical universality can be characterized by scaling laws considered to be at the heart of econophysics[11] (Bouchaud 2002; or Stanley et al. 2007, p. 288). These scaling laws can take a variety of forms and, according to most econophysicists (Mandelbrot 2004; McCauley, 2004), economic complex systems[12] obey a specific kind of invariance that can be characterized by power law[13] distributions of the form: $p(x) \sim x^{-\alpha}$, where p(x) is the probability of there being an event of magnitude x, and

[8]Mongin (2002) or Lallement (2000).

[9]On this point, Kirman (1989) explained the "the problem [of mainstream theorizing to date] seems to be embodied in what is an essential feature of a centuries-long tradition in economics, that of treating individuals as acting independently of each other" (Kirman 1989, p. 137).

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

[11]These scaling laws then can be viewed as a macro-result of the behavior of a large number of interacting components from lower levels. As Rickles (2008, p. 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 also are used to characterize many phenomena in social sciences (the ranking of firm size [Stanley et al. 1996], the income distribution of companies [Okuyama et al. 1999], fluctuations in finance [Mandelbrot 1997]), these laws often are substituted for by log-normal laws in which the variance parameter is not infinite.

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

the scaling exponent α is a constant whose value is set either by the empirically observed behavior of the system, by a theory, or by simulations.

III. THE POSITION OF ECONOPHYSICS IN THE DISCIPLINARY SPACE

Given that econophysics is based on different fundamental assumptions from those of mainstream economics, an analysis of the publication venues should give us a good idea of the position of that new field in the space of scientific disciplines. From what we have already said about econophysics being promoted by "outsiders" to the discipline of economics, and given that this discipline is very autonomous and has a strong tendency to refer essentially to itself,[14] we should expect econophysicists to have difficulty publishing their results in the major economics journals.

In order to reconstruct the subfield of econophysics, we started with the group of the most influential authors in econophysics, and tracked their papers in the literature using the Web of Science database of Thomson-Reuters.[15] We identified a group of 242 source papers covering the domain of econophysics, and the papers that cite them over the period 1980 to 2008, to analyze the evolution of the field. Starting with these core papers, which serve to construct the population of researchers, we then identified 1817 other papers that cited the source articles. The core papers being central to econophysics, we estimated that papers citing them would, in all probability, also be discussing econophysics. Analyzing all the cited authors in those papers shows that, indeed, all the usual figures associated with econophysics are well cited.[16]

As shown in Table 1, more than 70% of the key papers that have been published since 1996 appear in physics journals, while only 21.6% found their place in either economics or finance journals. For the previous period (1980 to 1995), there were very few papers written by the source authors. They were written mainly by economists, and were not based on a physics approach.[17] However, economists who

[14]Pieters and Baumgartner (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. Moreover, according to the *Science & Engineering Indicator*s (2000, table 6–54, p. 103), 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 cites physics journals in about 80% of its references. These data are consistent with Whitley's (1986) characterization of economics as a "partitioned bureaucracy" with a strong control over its theoretical core.

[15]The sample is composed of: Eugene Stanley, Rosario Mantegna, Joseph McCauley, Jean-Pierre Bouchaud, Mauro Gallegati, Benoît Mandelbrot, Didier Sornette, Thomas Lux, Bikas Chakrabarti, and Doyne Farmer. We could have added other names but the objective of this research is to identify the main bibliographic trends in econophysics. Moreover, given the usual practice of citations, we would retrieve other important authors through the analysis of the cited references in these papers as well as in the papers citing those source papers.

[16]We found that the core of econophysics essentially is composed of five authors: Mantegna, Bouchaud, Mandelbrot, Sornette, and Lux, who are, by far, the most-cited authors in our 1817 papers. All the others are also cited, though on a lesser scale.

[17]These papers were written mainly by Thomas Lux and Mauro Gallegati, and dealt with macroeconomics (Lux 1992a, 1992b; Gallegati 1990, 1994) or history of economics (Gallegati, 1992).

Table 1. Disciplines in which the source papers have been published (*Web of Science*)

Dicipline	1980-1995	%	1996-2008	%	Total	%
Physics	8	32.0%	153	70.5%	161	66.5%
Economics & Finance	13	52.0%	47	21.6%	60	24.2%
Economics	13	52.0%	35	16.1%	48	19.8%
Finance	0	0.0%	12	5.5%	12	5.0%
Mathematics	0	0.0%	9	4.1%	9	3.7%
Other fields	1	16.0%	3	3.8%	4	5%
Total	25	100%	217	100%	242	100%

are interested in econophysics (Lux or Gallegati, for example) do not write only papers about econophysics. They have been trained as economists, and they also write papers about economics (mainly macroeconomics). This shows that the papers of Mandelbrot and Fama in the 1960s are not the only connection between economics and econophysics. There are also contemporary economists who make connections between these two fields.

The data shown in Table 1 point to a specific trend: papers promoting a physics approach to economics did not find a place in the mainstream of the discipline, and moved in the shadow of physics. A reliable measure of rejected submissions is difficult to obtain, but, as we show in the conclusion, the main actors of econophysics did try to publish in those mainstream economics journals, although without much success. So, the trend is not simply the effect of self-exclusion but also reflects a resistance on the part of mainstream economics.

Table 2 shows that one single physics journal, *Physica A,* devoted to "statistical mechanics and its applications," published by far the largest number of econophysics papers, with 41% of the total of the second period (1996 to 2008). It has, thus, become the leading journal of this new field, the second being another physics journal, the *European Physical Journal B,* devoted to Condensed Matter and Complex Systems. Moreover, one of the four editors of *Physica A* is the inventor of the term "econophysics": H. Eugene Stanley. Note that whereas one can consider that mainstream economics is centered in the USA, it seems that the center of econophysics is in Europe, where *Physica A* and the *European Physical Journal* are edited. An analysis of the institutional affiliations of the authors shows a real geographical divide, since 72% of our source papers are from European institutions, while only 16% are from American institutions.[18]

In Table 2, we see that only 4% of the key papers were published in *Physica A* between 1980 and 1996, when a majority of the papers still were published in

[18]Italian authors seem to be prolific, since more than 31% of the source papers are from Italy, while 29% are from French institutions, 5% come from Germany, and 3% from India. Note that the total is over 100%, since many papers are written in international collaborations. Econophysics being a weakly institutionalized new field, and the graduate programs being too recent to have produced many graduates, it is not possible yet to follow the careers of students, and the diffusion of ideas and methods through institutions.

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Table 2. Journals where the source papers have been published (*Web of Science*)

Journals	1980-1995	%	1996-2008	%	Total	%
Physica A	1	4.0%	90	41.5%	91	37.6%
European Physical Journal B	0	0.0%	27	12.4%	27	11.2%
Journal of Economic Behavior & Organization	2	8.0%	9	4.1%	11	4.5%
Quantitative Finance	0	0.0%	10	4.6%	10	4.1%
Physical Review E	0	0.0%	8	3.7%	8	3.3%

economics. Taken together, tables 1 and 2 suggest that the resistance to the ideas of ecconophysics was such that after 1995, the promoters of econophysics created their own niche outside economics and finance in order to publish their results. This is consistent with Whitley's observation that "research which ignores current priorities and approaches and challenges current standards and ideals is unlikely to be published in academic journals" of the discipline (Whitley 1986, p. 192).

Since the appointment of J.B. Rosser[19] as editor-in-chief in 2002, the *Journal of Economic Behavior & Organization* has begun publishing regular articles on the issue of complexity in economics, allowing econophysicists to publish their work in that journal. The fourth journal on the list, *Quantitative Finance,* is a relatively new one. As we will see below, it was created in 2001, and can be considered one of the first non-physics journals specifically devoted to the new field, as its editorial board includes many econophysicists and the two editors are an econophysicist (Jean-Philippe Bouchaud) and a mathematician (Micheal Dempster).

The centrality of physics for econophysics is clearly visible in Figure 1, which maps the network of co-citations between journals cited in papers citing our 242 source papers in econophysics. The dense core of the network is composed of physics journals, while economics and finance journals are peripheral (north-west on the map) and *Quantitative Finance* is in-between.

Another way to look at the centrality of physics journals is provided in Table 3, which shows that between 1996 and 2008, only 12% of the citations came from economics or finance journals, even if the explicit topic of econophysics papers were economic and financial phenomena. Interestingly, this trend was similar in the previous period (1980 to 1995), even as more than half the papers had been published in economics and finance journals. Econophysics, thus, essentially is discussed in physics journals, a result confirmed by Table 4, which shows that, for both periods, about three-quarters of the citations come from papers published in physics journals usually devoted to condensed matter and statistical mechanics.

In addition to the two journals already identified as the "core" of econophysics, we find *Physical Review E*, the major American physics journal devoted to research on "statistical, nonlinear and soft-matter physics." The only economics-related

[19]His research focuses partly on complexity in economics, a topic that may bring him to be more open to the approach proposed by econophysicists.

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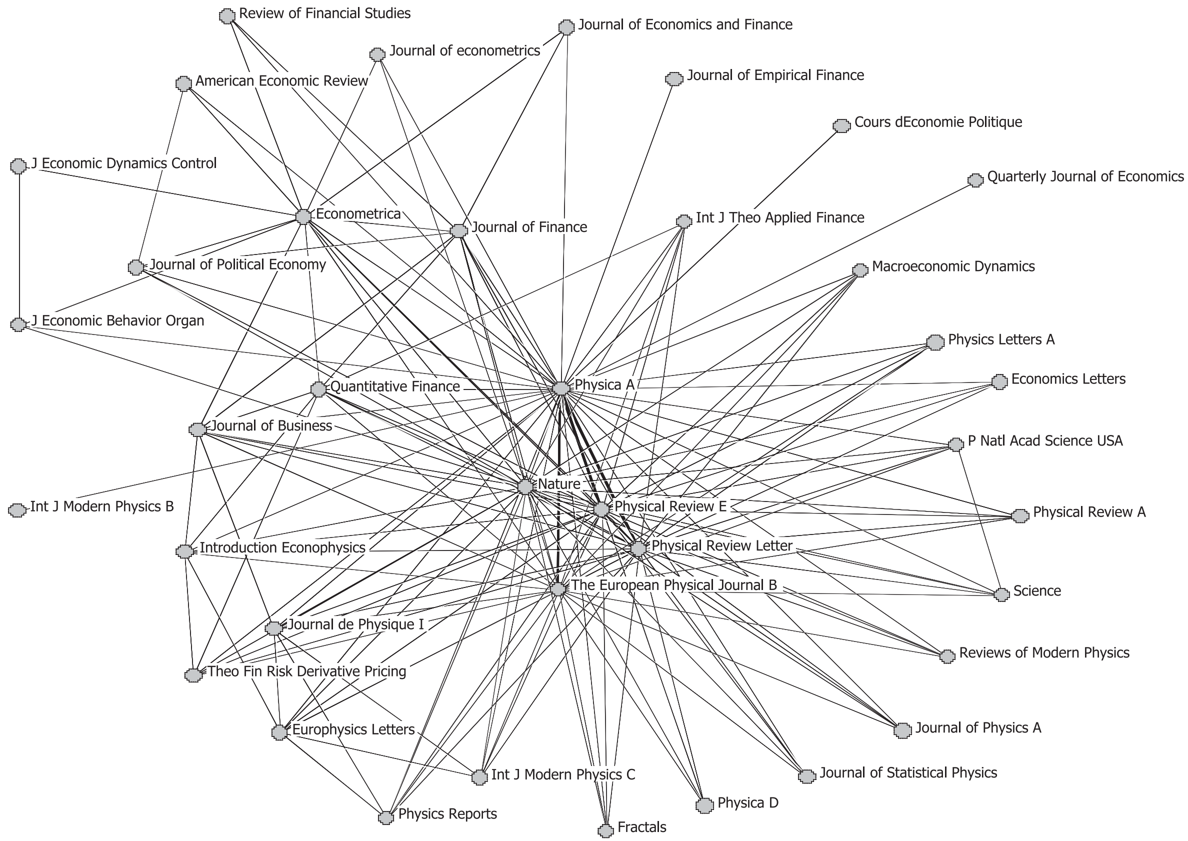

FIGURE 1: Most co-cited journals (and manuals) in papers citing our 242 source articles in econophysics (100 co-citations +), 1980-2008.

Table 3. Disciplines citing the source papers (*Web of Science*)

Discipline	1980-1995	%	1996-2008	%	Total	%
Physics	16	76.2%	2489	76.1%	2505	76.1%
Economics	2	9.5%	256	7.8%	258	7.8%
Finance	0	0.0%	143	4.4%	143	4.4%
Mathematics	1	4.8%	112	3.4%	113	3.4%
Other fields	1	9.5%	63	8.3%	64	8.3%
Total	21	100%	3272	100%	3293	100%

journals citing econophysics are *Quantitative Finance*, *Journal of Economic Dynamics and Control, Journal of Economic Behavior & Organization,* and *Macroeconomic Dynamics*. While the first is managed by econophysicists, the macro-dimension of the latter leads its editors to be more open to an econophysics perspective. A recent special issue entitled "Applications of Statistical Physics in Economics and Finance," published in 2008 by the *Journal of Economic Dynamics and Control,* explicitly proposed to "overcome the lack of communication between economists and econophysicists" (Farmer and Lux 2008, p. 3). Doyne Farmer and Thomas Lux[20] were the guest editors for this special issue, whose articles have been written by economists and physicists. As these authors noted in their editorial, 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" (Framer and Lux 2008, p. 3). In order to overcome the gap between the two camps, this special issue offered twelve articles dedicated to econophysics, written by authors coming from economics as well as from physics.

Another journal, *Quantitative Finance,* appears to be the main economics journal to publish many papers devoted to econophysics. Interestingly, in 2008 the most-cited journal in this publication is *Physica A,* followed by *Quantitative Finance* itself, the *Journal of Economic Dynamics and Control,* and then by two physics journals (*European Physical Journal B* and *Physical Review E*).[21] We should emphasize that economic-related journals citing econophysics cannot really be considered as mainstream journals in economics but, rather, as what Backhouse (2004, p. 265) called "orthodox dissenter" journals; that is, journals that are still rooted in mainstream theory but are open to other approaches.[22] All this suggests that the "mainstream" journals are not very open nor interested in publishing papers dedicated to econophysics.

[20]The first is physicist and the second is economist, and both were in our source authors.
[21]The data on the cited journals come from the [3]Journal of Citation Report 2008,[2] on the Web of knowledge of Thomson Reuters
[22]Following Backhouse (2004, p. 265), we distinguish "orthodox dissenters" from "heterodox dissenters"; the latter reject the mainstream theory and aim at deeply changing conventional ideas, while the former are critical but work within mainstream economics.

Table 4. Main journals citing the source papers (*Web of Science*)

Journals	1980-1995	%	1996-2008	%	Total	%
Physica A	3	14.3%	1213	37.1%	1216	36.9%
European Physical Journal B	0	0.0%	326	10.0%	326	9.9%
Physical Review E	2	9.5%	279	8.5%	281	8.5%
International Journal of Modern Physics C	1	4.8%	143	4.4%	144	4.4%
Quantitative Finance	0	0.0%	110	3.4%	110	3.3%
Journal of Economic Dynamics and Control	0	0.0%	68	2.1%	68	2.1%
Journal of Economic Behavior & Organization	1	4.8%	60	1.8%	61	1.9%
Acta Physica Polonica B	0	0.0%	42	1.3%	42	1.3%
Physical Review Letters	1	4.8%	36	1.1%	37	1.1%
Chaos Solitons & Fractals	0	0.0%	35	1.1%	35	1.1%
Journal of Physics A–Mathematical and General	1	4.8%	33	1.0%	34	1.0%
Macroeconomic Dynamics	0	0.0%	33	1.0%	33	1.0%
Journal of the Korean Physical Society	0	0.0%	30	0.9%	30	0.9%
Europhysics Letters	0	0.0%	29	0.9%	29	0.9%
Proceedings of the National Academy of Sciences of the United States of America	0	0.0%	25	0.8%	25	0.8%
Advances in Complex Systems	0	0.0%	24	0.7%	24	0.7%
Physics Reports–Review Section of Physics Letters	0	0.0%	24	0.7%	24	0.7%
Computer Physics Communications	0	0.0%	20	0.6%	20	0.6%
EPL	0	0.0%	20	0.6%	20	0.6%
International Journal of Bifurcation and Chaos	0	0.0%	20	0.6%	20	0.6%
Reports on Progress in Physics	0	0.0%	19	0.6%	19	0.6%
International Journal of Modern Physics B	0	0.0%	18	0.6%	18	0.5%
Journal of Statistical Mechanics–Theory and Experiment	0	0.0%	15	0.5%	15	0.5%

The complete absence of mainstream economic journals from Table 4 again confirms that, between 1996 and 2008, this discipline was not influenced much by econophysics, and does not really acknowledge its existence. By contrast, Table 5 shows that econophysics does depend on economic and finance journals, since nearly half the total of its citations (46.5%) goes to these disciplines, though physics still remains an important reference, with about a third of the citations going to papers published in physics journals, followed by mathematics journals for about 7% and

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Table 5. Disciplines cited in the source papers (two citations or more) (*Web of Science*)

Discipline	1980-1995	%	1996-2008	%	Total	%
Economics	148	50.7%	1559	26.7%	1707	27.9%
Finance	20	6.8%	1162	19.8%	1182	19.4%
Physics	56	19.2%	1943	33.3%	1999	32.6%
Mathematics	21	7.2%	419	7.2%	440	7.2%
Other fields	47	15.9%	752	13%	799	12.9%
Total	292	100%	5835	100%	6127	100%

a tail of many different science journals (13%). During the first period (1980 to 1995), more than 56% of the references cited were to economics or finance journals. Thus, we observe a decreasing dependence of econophysics on the economics literature and a growing presence of physics journals as a source of knowledge for econophysics, up from 19.2% to 32.6%, which again is consistent with a development of that field essentially outside the field of economics.

This trend can be observed also in Table 6, which lists the main journals cited in the source papers. While economics journals (*American Economic Review)* often were cited in the key papers written between 1980 and 1995, physics journals became the main source of knowledge for the papers published after 1996.

Taken together, these data confirm that as a field, econophysics is building on the existing institutional structures of physics instead of trying to impose itself inside the existing field of economics. A measure of the rapid growth of that field within physics is provided by Table 7, showing the evolution of the annual number and proportion of papers devoted to that topic in *Physica A* since 1996.

The trend is clear despite an exceptional year in 2007 when two special issues of the journal were devoted to econophysics. A similar trend (not shown here) is observed in the *European Journal of Physics B*. The growing presence of econophysics in the pages of physics journals probably has contributed to the official recognition of the field by the Physics and Astrophysics Classification Scheme (PACS), and econophysics has been, since 2003, an official subcategory of physics under the code *89.65 Gh* .

The openness of physics journals to topics such as econophysics contrasts strongly with the closure of mainstream economics journals to that topic. Though more research will have to be done on that question, it is probable that this openness of physics to non-physical topics is related to the fact that model building has become a self-conscious and important part of the practice of physics as compared with the search for new laws. As a consequence, there may have been more sensitivity on the part of physicists to search for new phenomena to be modeled using their tools. In addition, such a wide view of their field could open up new job avenues for physicists at a time when the job market was difficult. While many physicists turned toward biology, some, especially statistical and condensed matter physicists, turned to social phenomena under the rubric of "sociophysics" and "econophysics," either as full-time or part-time research programs, as many were working in physics-related departments. It was easier to present their work to physics journals as example of

Table 6. Main journals cited in the source papers (two citations or more) (*Web of Science)*

Revues	1980-1995	%	1996-2008	%	Total	%
Physica A	3	1.0%	551	9.4%	554	9.0%
European Physical Journal B	0	0.0%	260	4.5%	260	4.2%
Physical Review E	0	0.0%	196	3.4%	196	3.2%
Quantitative Finance	0	0.0%	179	3.1%	179	2.9%
Physical Review Letter	5	1.7%	162	2.8%	167	2.7%
Nature	2	0.7%	147	2.5%	149	2.4%
Journal of Finance	2	0.7%	128	2.2%	130	2.1%
American Economic Review	18	6.2%	107	1.8%	125	2.0%
International Journal of Theoretical and Applied Science	0	0.0%	113	1.9%	113	1.8%
Econometrica	7	2.4%	101	1.7%	108	1.8%
International Journal of Modern Physics C	0	0.0%	107	1.8%	107	1.7%
Journal de Physique I	2	0.7%	93	1.6%	95	1.6%
Journal of Business	6	2.1%	85	1.5%	91	1.5%
Journal of Economic Behavior & Organisation	5	1.7%	84	1.4%	89	1.5%
Journal of Political Economy	5	1.7%	73	1.3%	78	1.3%
Quarterly Journal of Economics	10	3.4%	62	1.1%	72	1.2%
Economic Journal	10	3.4%	58	1.0%	68	1.1%

modeling exercises analogous to those found in physics than to try to pass through the gatekeepers of economic and financial journals. The difficulty was compounded by the fact, already mentioned, that the conceptual foundations behind the mathematical techniques are very different from those found in mainstream economics. In fact, the conceptual and methodological specificity of econophysics is closely linked to the different disciplinary origins of the authors who promote that research program, as most have been trained as physicists and not as economists. Econophysics is, therefore, a field developed mainly by authors who have been trained as physicists and who work now in a physics department. That is the case for eight of our key authors. Of course, some economists are interested in econophysics: Thomas Lux and Mauro Gallegati, for example, are leading authors in econophysics, and both have been trained as economists.

IV. THE INSTITUTIONALIZATION OF ECONOPHYSICS

If the 1990s saw the emergence and growth of econophysics as a research program, the next decade witnessed the growing institutionalization of this field. Though papers could be published in existing physics outlets, the specialty could develop further by having its own specialized conferences, journals, textbooks, and training programs.

A simple and practical way to spread knowledge relating to econophysics as a new paradigm is to organize workshops and colloquia. The first conference devoted to

Table 7. Number of papers dedicated to econophysics published in the *Physica A* journal (*Web of Science*)

Year	Number of papers dedicated to econophysics	Total number of papers published	Proportion devoted to econophysics (%)
1996	1	486	0.2
1997	9	627	1.4
1998	7	582	1.2
1999	29	608	4.7
2000	53	636	8.3
2001	74	646	11.4
2002	44	674	6.5
2003	118	770	15.3
2004	162	853	18.9
2005	112	713	15.7
2006	115	848	13.5
2007	209	1028	20.3
2008	131	715	18.3
2009	84	558	15

econophysics took place in Budapest in 1997. Unsurprisingly, it was organized by the department of physics of the university. Two years later, the European Association of Physicists officially endorsed the first conference on Application of Physics in Financial Analysis (APFA), which was organized in Dublin. The APFA colloquium was entirely dedicated to econophysics, and it was organized annually until 2007. There now exist several annual conferences dedicated to econophysics, such as the Nikkei Econophysics Research workshop and symposium, and the Econophysics Colloquium. Combined with publications of papers through specialized journals devoted to the field, and textbooks, these events contribute to the stabilization and spread of a common scientific culture among econophysicists. As for scientific societies, one can point to the creation in 2006 of the Society for Economic Science with Heterogeneous Interacting Agents (ESHIA), which aims at promoting interdisciplinary exchanges among economists, physicists, and computer scientists (essentially in artificial intelligence), an objective consistent with econophysics. The absence of the label in the name of the organization may be a way to bring more economists on board by letting their discipline keep its own name instead of being swallowed by the new term, a gesture that would surely be perceived as hostile and imperialistic.

One can consider *Quantitative Finance*, created in 2001, to be a journal essentially devoted to questions of econophysics (their editorial boards include many econophysicists), followed by the *Journal of Economic Interaction and Coordination (JEIC)*, which started in 2005. As mentioned above, the *Journal of Economic Dynamics and Control* is also open to papers related to econophysics, since this journal published recently a special issue devoted to this theme.

The first textbook, entitled *Introduction to Econophysics,* was published in 2000 by Mantegna and Stanley. Though several have appeared since (Roehner 2002, and

McCauley 2004, for example). As Figure 1 shows, this first textbook remains the most central to the field. The aim of such textbooks is to define and stabilize the contour of the field as well as its methods, thus helping to create a shared culture uniting the members of the new specialty. As such, they constitute an important step in the process of institutionalization of the field. As Jovanovic notes (2008, p. 219), "Given that collections of articles are published before textbooks, the interval between the moment when the former were published and the moment when the textbooks were published gives an indication about the evolution of the discipline." The swiftness of the development of econophysics can be gauged by noting that it took twice as long (that is, two decades) to have the first textbooks devoted to another recent specialty: behavioral finance (Schinckus 2009b).

A last important component of a truly institutionalized research field is the creation of new academic courses, and the organization of training MA and PhD programs uniquely devoted to that field. Here again, the physics discipline served as the institutional basis, and several physics departments have offered courses in econophysics since 2002 (universities of Ulm in Sweden, Fribourg in Switzerland, Munster in Germany, Wrolcaw in Poland, and Dublin in Ireland). Usually, these courses are framed for physicists, and focus on statistical physics applied to finance. An additional step in the institutionalization of econophysics has been the creation of full academic programs totally dedicated to econophysics. The first universities to offer complete programs leading to a diploma were Polish, where Warsaw proposed a Bachelor and Wrolcaw a Master. In 2006, the university of Houston (USA) was the first to coordinate a PhD in econophysics,[23] and in 2009, the university of Melbourne (Australia) planned to launch a similar program.[24] All are part of physics departments and, therefore, physics-oriented. In order to familiarize students with the economic reality they are supposed to describe, these programs do provide some courses on the financial and macroeconomic *reality,* but they are not based on the *theoretical* basis of finance and macroeconomics.[25]

All these new academic programs show that econophysics is developing outside the social sciences and the discipline of economics, as a new scientific community with its own journals, conferences, and training programs. Since the middle of the 2000s, the conditions for the production of knowledge and the long-term reproduction of the group of econophysicists are now in place, and provide the basis for a sustained growth in the annual number of publications.

V. CONCLUSION: WHAT KIND OF FUTURE FOR ECONOPHYSICS?

Since econophysics claims to explain economic and financial phenomena, one would think that the central disciplines devoted to these phenomena (namely, economics and finance) would have played a central role in the emergence of econophysics. But as we have shown, this was far from being the case, and it developed in relative autarchy

[23] See the website: http://phys.uh.edu/research/econophysics/index.php.
[24] http://physics.unimelb.edu.au/Community/Newsroom/News/Econophysics-scholarship-available
[25] For further information on these programs, see Kutner and Grech (2008, p. 644), and the website of these universities. See University of Houston (http://phys.uh.edu/research/econophysics/index.php); on the organization of BSc and Master in econophysics at the University of Warsaw, see Kutner and Grech (2008, p. 637).

and even in reaction to mainstream economics, which is a well-established discipline regulated by a strong dominant paradigm and a strong tendency to be closed on itself.

Three types of reasons might explain the difficulty for econophysicists to publish their work in standard economics journals: methodological, geographical, and sociological. As mentioned before, there is a methodological gap between these two "false sister disciplines" (Schinckus 2010b). Economics is a theory-based discipline founded on a micro-perspective that gives a central place to the notion of equilibrium (Mosini 2007). By constrast, econophysics is an empiricist and data-driven field founded on a macro-approach in which the notion of equilibrium does not necessarily play a key role (Schinckus 2010a, 2010c).[26] We have noted the fact that econophysics appears centered in European institutions while mainstream economics often is said to be dominant in American institutions (Maes and Buyst 2005). This geographic distinction could contribute to the lack of contact between the two communities.

Concerning the more sociological aspect of the divide, Whitley (1986) presented economics as a "reputationaly 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 the marginalization of all anomalies or empirical contradictions with 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 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 the 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 way to understand economics, as the usual Gaussian curves are replaced by power laws 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 instead on the interactions that give rise to complex phenomena that can be described through interactions between its parts.[27] 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, as happened for other new specialties such as behavioral finance or

[26]Of course, the notion of equilibrium often is used by econophysicists but not necessarily as an *a priori* idea as it is in mainstream economics. In econophysics, this concept is considered as a potential state of the system. When econophysicists deal with equilibrium, they refer to a "statistical equilibrium" coming from statistical mechanics. See Bouchaud (2002).

[27]See Schinckus (2010a) for a presentation of the main differences between economics and econophysics.

experimental economics. The sociological reasons, combined with the conceptual differences between economists and econophysicists, led to a scientific confinement of econophysics that then appeared as a new field developed *by physicists for physicists*.

One might think that economists don't really 'reject' econophysicists, but that the latter just don't want to publish in mainstream economic journals. That, however, is not the case. First, we showed that econophysicists have created new journals (*Quantitative Finance* and *JEIC*) in economics (and not in physics) in order to reach finance economists and access an audience outside that of econophysicists. Second, since they work on the same phenomena as economists, we should expect that econophysicists did try to publish in economic journals. To test that hypothesis, Jovanovic and Schinckus (2010b) did an informal survey by sending a questionnaire to twenty-seven leading econophysicists (included as source authors in our analysis) about the degree of closure of economic 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 why their papers were rejected, they replied that referees in economic journals often have difficulties with the topic or/and the method used in their papers.[28] Though based on a small sample, but including the central figures of econophysics, these results strongly suggest that economic journals are, in fact, reluctant to publish papers dedicated to econophysics. It seems that only after having faced this resistance have econophysicists reacted by excluding themselves and moving towards journals more open to the econophysics perspective.

Given the strong institutional basis of mainstream economics, and the fact that econophysics develops as a kind of "refugee" in the house of physics, one can ask what the future will be for that field of research: will its basic intuitions be integrated into economics, or will the development continue to be completely independent ?

Our bibliometric analysis of the emergence of econophysics shows that physics journals have become the main venue for publishing econophysics papers, a trend combined with the decreasing proportion of citations coming from the economics and finance literature. This trend makes sense from a sociological point of view. As mentioned before, economics is an institutionalized discipline with strong control over its theoretical goals. In this context, all new contributions in economics have to conform to the collective standard and priorities of the mainstream (Whitley 1986). Econophysics appears as a theoretical innovation that is not in line with the ideals, goals, and standards of economics (McCauley 2006; Schinckus 2010b). Since 1996, econophysics has been growing rapidly, and its papers have found a niche in a few physics journals (especially *Physica A*) that opened their pages to a field nearer to the social than the natural sciences, thus extending the area of application of their tools. As new papers devoted to econophysics necessarily will cite the existing econophysics papers, which have been published in physics journals, the trend probably will be toward an even greater autonomy of that field, which will continue to use physics journals as a basis in addition to the new journals specifically devoted to that

[28]They had to choose between five reasons for having been rejected, and they 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. For details, see Jovanovic and Schinckus (2010b).

field. For, as long as econophysicists will work in physics departments, they probably will continue to publish, at least in part, in physics journals in order to be perceived by their institution and colleagues as still being "physicists." As a consequence, economics journals probably will continue to decline as source of references for econophysics.

Therefore, there is a dynamic of repulsion between economics and econophysics; as Whitley observed, "economics has a strong hierarchy of journals" (Whitley 1986, p. 192), and researchers who do not conform to the dominant standards are bound to publish outside that core. They will be viewed as irrelevant to the core and forced to publish in new journals not recognized by the mainstream of the discipline. While this tendency could have given rise to a new specialty among the social sciences, the fact that the tools of econophysics were imported from physics, and that this discipline happened to be open to accepting as legitimate the modeling of social phenomena (thus enlarging its scope and possible job market), brought econophysics in the shadow of physics, because it first grew by using existing physics journals for publication and physics departments as training ground for the new breed of "econophysicists."

Given such a repulsive dynamic, and even if at least some of the results from econophysics could, in principle, be integrated in the mainstream, this field probably will continue to become more independent from economics. The particular form taken by the institutionalization of graduate training in econophysics, which passes, as we have shown, through physics departments, means it could, in the long run, become a new specialty of physics rather than of economics, despite the common object of both fields.

One can also imagine that the recent major financial crisis, which, in turn, created an intellectual crisis among many economists (Colander et al. 2008), could lead to a reorganization of the discipline in which econophysics would be seen as helping to move toward a new paradigm. However, the previous crisis of macroeconomics, much discussed at the beginning the 1980s, did not lead to a major refurbishing of the analytic core of the discipline (Bell and Kristol 1981; Whitley 1986, p. 203). It is unlikely that the present crisis will lead to a real integration of econophysics as a legitimate part of the economic discipline. Indeed, even if, as Colander et al. (2008, p.22) suggested, "the global financial crisis has revealed the need to rethink fundamentally how financial systems are regulated, it has also made clear a systemic failure of the economics profession." However, they also note, the influences of economic crisis on a potential evolution of the economic theory always takes time. Moreover, as Whitley explained, "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 1986, p. 204). Also, econophysicists will have to sell their expertise on the market before being able to dislodge the mainstream of the economic discipline. Only when banks and financial institutions start to hire many graduates from the new econophysics programs offered by physics departments will economic departments begin to take notice and adapt their programs in consequence, in order to keep being competitive on the job market for their graduates.

Econophysics can be seen as the re-emergence of an old (1960s) technical problem, previously discussed in economics and related to the impossibility of giving an economic interpretation to an indeterminate variance. This re-emergence under the name of ''econophysics'' offers a unique[29] case of a specialty in a field that has developed outside its natural *social* science discipline and found a niche inside a *natural* science (physics), surviving and growing despite its rejection by mainstream economics. It also provides a very interesting case study of the difficulty of innovating inside a field characterized by a strong orthodoxy and an inability to accept different and competing paradigms as legitimate. Finally, one could see an irony in the fact that though economics often has suffered from ''physics envy'' and imported tools from that field, econophysics failed to be incorporated into economics. This failure may be due, in part, to the fact that the two disciplines have very different foundations (Schinckus 2010b). Another irony may lie in the fact that economics often has been perceived as imperialistic, and now sees itself attacked by another imperialist discipline: physics.

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[29]This case is different from that of extending economic analysis to social or political questions, as economics is itself a description of *social* phenomena, and, therefore, it can be seen as q part of social sciences even if it is often more mathematized. Moreover, these approaches are accepted in sociology and political science departments, and do not constitute a case of an approach external to these disciplines. By contrast, econophysics comes from natural sciences, and its methodology has been developed in order to describe non-human phenomena. More importantly, as we show in the paper, this approach has not been developed in economics departments but in physics departments. A better example would be the so-called ''sociophysics'' (Galam 2004), which is similar to econophysics but more general as it is applied to all kinds of social phenomena. Preliminary analysis along the lines developed in this paper show that, like econophysics, sociophysics developed outside sociology and the social sciences, and remains marginal: it is cited rarely by the central journals of the social sciences.

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