GUEST COMMENT

Econophysics and economics: Sister disciplines?

Econophysics is an interdisciplinary field that applies various models and concepts associated with statistical physics to economic and financial phenomena. At first glance, it might be thought that economics and econophysics share the same kind of analysis of economic reality. I argue that economics and econophysics are very different. Although the former is an *a priori* social science, the latter has its methodological roots in the physical sciences.

Econophysics is a hybrid discipline whose name[1] results from the contraction of "economics" and "physics."[2] Econophysics is not just a new fashion in the set of existing economic theories. It is a new way of thinking about economic and financial systems based on the universality of statistical properties and complexity. Econophysicists use the tools and concepts of statistical physics[3] and complexity science[4] to describe socioeconomic systems (markets, companies, and national economies) as complex systems.

Econophysics is a new discipline that has generated several methodological debates.[5] More and more papers on econophysics have been published in journals devoted to physics and statistical mechanics.[6] Several meetings dedicated to this topic are regularly organized,[7] and new Ph.D. programs in econophysics have recently appeared.[8]

Are econophysics and economics complementary fields or totally separated disciplines? In this paper I argue that econophysics is not a subfield of economics, and these two fields are separate disciplines.

There are two kinds of gaps between economics and econophysics. The methodological gap refers to a way of doing science. Although economists base their work on *a priori* methodology, econophycisists use a *data-driven* methodology. The other gap concerns the way they think about reality. Econophycisists and economists do not see the world in the same way.

In contrast to econophysics, economics is not an empirical discipline. Even if there are debates about the empirical dimension of economics,[9] the empirical dimension in economics is exaggerated.[10] According to econophysicists, complexity studies need an empirical basis.[11] "The real empirical data are certainly at the core of this whole enterprise [econophysics] and the models are built around it, rather than some non-existent, ideal market [as in economics]."[12] This empirical dimension is frequently mentioned in econophysical research[13] and is often presented as the main difference with economics.[14]

This difference between economics and econophysics can be illustrated by considering fat tails or financial crashes. Economists assume that price changes obey a lognormal probability distribution with a near zero kurtosis (a mesokurtic distribution). This *a priori* perspective implies that massive fluctuations have a very small probability. However, real data show a positive kurtosis and a leptokurtic distribution in which extreme events have a higher probability of occurring.[15] By beginning with observed data, econophysicists develop models in which some extreme events such as a financial crash can occur.[16] This *a priori* thinking leads economists to underestimate the occurrence of financial crashes. "The standard theory, as taught in business school around the world, would estimate the odds of that final, August 31 [1998] collapse at one in 20 million—an event that, if you traded daily for nearly 100 000 years, you would not expect to see even once."[15] However, several financial crisis were observed during the past century, and therefore economic theory seems to be unable to describe this kind of phenomena.[17,18]

Due to this *a priori* approach and inability to describe the real world, there is in the econophysics literature an explicit rejection of the key concepts from modern economic theory that are considered as empirically and logical flawed.[13] Most economists develop abstract models with many unrealistic restrictions to assure the theoretical stability of their models. They have an *a priori* model and try to shape their data to find their *a priori* principles in reality.[19] This a-priorist approach is rejected by econophysicists, who work on data-driven models that are developed to describe economic reality. While economists invent economic reality, econophysicists try to describe it.

The other gap is that econophysicists and economists do not work in the same paradigm. "Arguably the clearest contrast between the approach of econophysicists and more regular economists, has been in the conviction of the former that many of these phenomena can be better described using scaling laws that imply non-Gaussian distributions exhibiting skewness and leptokurtis rather than a Gaussian distribution."[20] The ways of using probability and reducing uncertainty are not the same in economics and in econophysics. In economics, theoreticians reduce uncertainty to risk by using some statistical transformations to achieve a Gaussian world and then apply statistical measurements. Therefore, in economics, uncertainty situations are reduced to *a priori* statistical models. This *a priori* perspective leads to confusion between uncertainty and risk (often reduced to the statistical variance of data). This kind of reduction is not a problem *per se.* The issue is about the *a priori* dimension (independent of reality) of economics and the fact that uncertainty is reduced to risk.[21] Economists tend to forget that their probabilistic approach to uncertainty is an incomplete representation of reality, and they substitute their models for uncertainty.

In econophysics the concept of uncertainty is not given by *a priori* model. The main objective is to provide a more operational form of uncertainty than neoclassical economics by developing several ways of modeling uncertainty. By providing a collection of operational instruments to study uncertainty situations, econophysics becomes to a more *uncertainty-oriented* discipline than economics.[22]

Epistemologically, econophysics is founded on the universality of statistical properties. This statistical universality is characterized by scaling laws that are at the heart of econophysics.[21] Scaling laws can be viewed as the macroresult of the behavior of interacting parts. These interactions are independent of the microscopic details and depend only on a few macroscopic parameters.[22] The scaling laws are emergent properties because they do not emerge causally and are not reducible to the sum of properties of the components.[23] Despite this diversity, complex economic systems seem to obey a kind of invariance that can be characterized by power law[24] distributions of the general form[25] $p(x) \sim x^{-\alpha}$, where $p(x)$ is the probability of an event of magnitude x and the scaling exponent α can be determined either by empirically observed behavior of the system or by a theory or simulation.

The real world described by econophysicists is not Gaussian. By using a more leptokurtic distribution, they find that extreme events have a significant probability to occur. Potential extreme events resulting from the complex systems are then taken into account in the econophysics approach. This consideration of extreme events is not observed in economics where stability is ensured by the Gaussian framework that makes the occurrence of extreme events very improbable. In this perspective, how can economists explain a financial crash?

Both economics and econophysics imply a particular reductionism.[26] Economic theory is based on an *atomistic reductionism* in which reality must be explained in terms of a rational representative agent; econophysics is more based on an *interactive reductionism* where complex phenomena can be described through interactions between its parts. This distinction is important because it involves some empirical implications. By basing all economic macrophenomena on the rational representative agent, economists implicitly set the marcolevel equal to the microlevel. The consequence is that all macroconcepts such as "market," "systemic risk," or "financial crisis" are misunderstood in economic theory. In this perspective it is impossible to describe and understand an economic crisis such as what we faced in 2008. As mentioned, econophysicists provide a theoretical framework that is adapted to the analysis of extreme events. Moreover, econophysicists focus their work on interactions between all parts composing the complex system. Because economic activity is interactive in essence, this perspective is more appropriate for understanding the connections between all parts of economic systems (firms, banks, and households) and the extreme events (a financial crisis) observed in economic reality.

Another fundamental difference between econophysicists and economists concerns the psychological assumptions about economic agents. In neoclassical economic theory, rationality appears to be fundamentally causal and explains all the individual agents' behaviors.[27] In this perspective all macrophenomena result from a *homopathic causalit*y, where the total effect of several causes acting in concert is identical to what would have been the sum of the effects of each of the individual causes (actors) acting alone.[28] Econophysicists do not care about rational agent theory. By considering that "market components" (including traders, speculators, and hedgers) obey statistical properties, most econophysicists avoid the difficult task of theorizing about the individual psychology of investors.[29] Only the macrolevel of the system can be observed and analyzed. Economic and financial systems consist of a large number of components whose interactions generate observable properties such as scaling laws, which are independent of microscopic details (individual behavior). These emergent properties are based on a *heteropathic causality*[30] because they cannot just be characterized by the sum of individual behaviors.

In conclusion, the methodological gap between econophysicists and economists is huge. The main differences between these two disciplines can summarized as follows: (1) Different ways of doing science (empiricism versus an *a priori* approach), (2) different use of the notion of model (data-driven models versus *a priori* models), (3) different way of characterizing the future (uncertainty-oriented versus risk-oriented), (4) differences concerning the potential occurrence of extreme events (instability versus stability), (5) different kind of reductionism (interactive versus atomistic), (6) different epistemological foundations (macrolevel versus microlevel), and (7) different kinds of causality (heteropathic versus homopathic causality).

ACKNOWLEDGMENTS

The author thanks the anonymous referees for their helpful comments. The author wishes to acknowledge the financial support of the Social Sciences and Humanities Research Council of Canada in carrying out this research.

[1] The official birth of the term "econophysics" dates back to a paper by H. Stanley, V. Afanasyev, L. A. N. Aamaral, S. V. Buldyrev, A. L. Goldberger, S. Havlin, H. Leschhorn, P. Maass, Rosario N. Mantegna, C.-K. Peng, P. A. Prince, M. A. Salinger, M. H. R. Stanley, and G. M. Viswanathan, "Anomalous fluctuations in the dynamics of complex systems: From DNA and physiology to econophysics," Physica A **224**, 302–321 (1996).

[2] Some authors consider the works of Walras or Pareto as a first application of physics in economics. See B. Roehner, *Patterns of Speculation: A Study in Observational Econophysics* (Cambridge U. P., Cambridge, 2005) or J. McCauley, *Dynamics of Markets* (Cambridge U. P., Cambridge, 2004). For further information about the influences of physical sciences on economics, see P. Mirowski, *More Heat than Light: Economics as Social Physics, Physics as Nature's Economics* (Cambridge U. P., Cambridge, 1991).

[3] Z. Burda, J. Jukiewicz, and M. Nowak, "Is econophysics a solid science?," Working Paper, Institute of Physics, Jagellonian University, Krakow (2003).

[4] E. Morin, *Introduction à la Pensée Complexe* (Editions du Seuil, Paris, 2005); D. Rickles, "Econophysics and the complexity of the financial markets," in *Handbook of the Philosophy of Science, Vol. 10: Philosophy and Complex Systems*, edited by J. Collier and C. Hooker (Elsevier, New York, 2008), pp. 1–40.

[5] T. Lux and M. Ausloos, "Market fluctuations I: Scaling, multiscaling, and their possible origins," in *The Science of Disasters: Climate Disruptions, Heart Attacks and Market Crashes*, edited by A. Bunde, J. Kropp, and H. Schnellnhuber (Springer, Berlin, 2002), pp. 373–409; Dean Rickles, "Econophysics for philosophers," Studies in the History and Philosophy of Modern Physics **38** (4), 948–978 (2007); Barkley Rosser, "The nature

and future of econophysics," Working Paper, James Madison University, pp. 1–16 (2005); Mauro Gallegati, Steve Keen, Thomas Lux, and Paul Ormerod, "Worrying trends in econophysics," Physica A **370**, 1–6 (2006).

[6] See, for example, the increasing number of papers dedicated to econophysics in Physica A and European Journal of Physics B.

[7] See ⟨PhysicsWorld.com⟩.

[8] See ⟨phys.uh.edu/research/econophysics/index.php⟩ and R. Kutner and D. Grech, "Report on foundation and organization of econophysics graduate courses at faculty of physics of University of Warsaw and Department of Physics and Astronomy of the Wrocław University," Acta Phys. Pol. A **114** (3), 637 (2008).

[9] M. Blaug, *The Methodology of Economics: Or How Economists Explain* (Cambridge U. P., Cambridge, 1992); D. Keita, *Science, Rationality and Neoclassical Economics* (University of Delaware, Baltimore, 1992).

[10] By exposing the ambiguity of economic propositions, Mongin shows that empiricism is not really the more appropriate framework to describe economic methodology. See Philippe Mongin, "L'analytique et le synthétique en économie," Cahiers de l'Ecole Polytechnique CNRS, No. 2003-005 (2003) and Philippe Mongin, "L'apriori et l'aposteriori en économie," Cahiers de l'Ecole Polytechnique CNRS, No. 2005-025 (2005) About this point see also L. Boland, *The Methodology of Economic Model Building: Methodology after Samuelson* (Routledge, London, 1989); L. Boland, *Critical Economic Methodology* (Routledge, London, 1997).

[11] Yougui Wang, Jinshan Wu, and Di Zengru, "Physics of econophysics," Working Paper of Beijing Normal University, No. 1025 (2006).

[12] See Rickles in Ref. 5.

[13] Steven Keen, "Standing on the toes of pygmies: Why econophysics must be careful of the economic foundations on which it builds," Physica A **324**, 108–116 (2003); Jean-Philippe Bouchaud, "An introduction to statistical finance," *ibid.* **313**, 238–251 (2002); A. Carbone, G. Kaniadakis, and M. Scarfone, "Where do we stand on econophysics?," *ibid.* **382**, 11–14 (2007).

[14] H. Stanley, X. Gabaix, and V. Plerou, "A statistical physics view of financial fluctuations: Evidence for scaling universality," Physica A **387**, 3967–3981 (2008).

[15] B. Mandelbrot, *The Misbehaviour of Markets* (Profile Group, London, 2004).

[16] Extreme events can be conceptualized through different econophysical frameworks, for example, as a phase transition. See N. Vandewalle, Ph. Boveroux, A. Minguet, and M. Ausloos, "The crash of October 1987 seen as a phase transition: amplitude and universality," Physica A **255**, 201–210 (1998).

[17] E. Kahana, "The history of the global financial crisis in the 20th century," Working Paper of the International Studies Association (2005).

[18] J. McCauley, *Dynamics of Markets: Econophysics and Finance* (Cambridge U. P., Cambridge, 2004).

[19] See W. F. Sharpe, "Capital asset prices: A theory of market equilibrium under conditions of risk," J. Financ. **19**, 425–442 (1964). For example, when Sharpe wrote his famous Capital Asset Pricing Model (which can be considered as a pillar of modern finance), he explained, "Needless to say, there are highly and undoubtedly unrealistic assumptions. However, since the proper test of a theory is not the realism of its assumptions but the acceptability of its implications, and since these assumptions imply equilibrium conditions which form a major part of classical financial doctrine, it is far from clear that this formulation should be rejected." The quote is on p. 427.

[20] See Rosser in Ref. 5.

[21] For more information about this point, see Christophe Schinckus, "Economic uncertainty and econophysics," Physica A **388**, 4415–4423 (2009).

[22] See Rickles in Ref. 4.

[23] K. Kitto, "Modelling and generating complex emergent behaviour," Ph.D. thesis, University of South Australia, The School of Chemistry, Physics and Earth Sciences (2006).

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

[25] This asymptotic equality means $p(x)$ becomes increasingly like a power-law as x goes to infinity. We often use fat tails to characterize complexity in economics. See G. M. Viswanathan, V. Afanasyev, S. V. Buldyrev, S. Havlin, M. G. E. da Luz, E. P. Raposo, and H. E. Stanley, "Levy flights in random searches," Physica A **282**, 1–12 (2000) The form of the distribution of these fat tails has the form $p(x) \sim x^{-(1-\alpha)}$. Some authors reserve the term "fat tail" for distributions only when $0 < \alpha < 2$. See J. Peinke, M. Siefert, S. Barth, C. Renner, F. Riess, M. Wächter, and R. Friedrich, *Fat Tail Statistics and Beyond* (Springer, Berlin, 2004).

[26] D. Colander, H. Follmer, A. Haas, M. Godber, K. Juselius, A. Kirman, T. Lux, and B. Slot, "The financial crisis and the systemic failure of academic finance," Working Paper GREQAM, University of Marseilles (2009).

[27] Philippe Mongin, "Le principe de rationalité et l'unicité des sciences sociales," Revue Economique **53** (2), 301–323 (2002); Jérome Lallement, "Popper et le principe de rationalité," Economies et Sociétés **21** (10), 25–40 (2000).

[28] T. O'Connor and H. Wong, "Emergent properties," in *Stanford Encyclopedia of Philosophy* (Edward N. Zalta Editions, London, 2005), ⟨plato.stanford.edu/entries/properties-emergent/⟩.

[29] O. Brandouy, in *Croyances, Représentations Collectives et Conventions en Finance*, edited by D. Bourghelle, O. Brandouy, R. Gillet, and A. Orléan (Economica, Paris, 2005).

[30] Cinla Akdere and Christophe Schinckus, "J. S. Mill and the origins of econophysics," Working Paper of the University of Paris I Panthéon-Sorbonne (2009).

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