

ECONOPHYSICS

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J. Barkley Rosser, Jr.
James Madison University
rosserjb@jmu.edu

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According to Bikas Chakrabarti (2005, p. 225), the term *econophysics* was neologized in 1995 at the second Statphys-Kolkata conference in Kolkata (formerly Calcutta), India by the physicist H. Eugene Stanley, who was also the first to use it in print (Stanley, 1996). Mantegna and Stanley (2000, pp. viii-ix) define “the multidisciplinary field of econophysics” as “a neologism that denotes the activities of physicists who are working on economics problems to test a variety of new conceptual approaches deriving from the physical sciences.”

The list of such problems has included distributions of returns in financial markets (Mantegna, 1991; Levy and Solomon, 1997; Bouchaud and Cont, 1998; Gopakrishnan, Plerou, Amaral, Meyer, and Stanley, 1999; Sornette and Johansen, 2001; Farmer and Joshi, 2004) the distribution of income and wealth (Drăgulescu and Yakovenko, 2001; Bouchaud and Mézard, 2000; Chatterjee, Yarlagadda, and Charkrabarti, 2005), the distribution of economic shocks and growth rate variations (Bak, Chen, Scheinkman, and Woodford, 1993; Canning, Amaral, Lee, Meyer, and Stanley, 1998), the distribution of firm sizes and growth rates (Stanley, Amaral, Buldyrev, Havlin, Leschhorn, Maass, Salinger, and Stanley, 1996; Takayasu and Okuyama, 1998; Botazzi and Secchi, 2003), the distribution of city sizes (Rosser, 1994; Gabaix, 1999), and the distribution of scientific discoveries (Plerou, Amaral, Gopakrishnan, Meyer, and Stanley, 1999; Sornette

and Zajdenweber, 1999), among other problems, all of which are seen at times not to follow normal or Gaussian patterns that can be described fully by mean and variance. The main sources of conceptual approaches from physics used by the econophysicists have been from models of statistical mechanics (Spitzer, 1971), geophysical models of earthquakes (Sornette, 2003), and “sandpile” models of avalanches, the latter involving self-organized criticality (Bak, 1996). An early physicist to assert the essential identity of statistical methods used in physics and the social sciences was Majorana (1942).

A common theme among those who identify themselves as econophysicists is that standard economic theory has been inadequate or insufficient to explain the non-Gaussian distributions empirically observed for various of these phenomena, such as “excessive” skewness and leptokurtotic “fat tails” (McCauley, 2004). With their sense of creating and developing a new science based on physics that is superior to the older conventional economics, many of the econophysicists have focused their publishing efforts in physics journals, notably *Physica A*, *Physical Review E*, and *European Physical Journal B* to name some of the most frequently used ones, along with the general science journal *Nature*, and some more clearly multidisciplinary journals such as *Quantitative Finance*. However, increasingly some of the econophysicists have begun to publish jointly with economists, with some of these papers appearing in economics journals as well. This should not be surprising in that the emergence of econophysics followed fairly shortly on the influential interactions and discussions that occurred between groups of physicists and economists at the Santa Fe Institute (Anderson, Arrow, and Pines, 1988; Arthur, Durlauf, and Lane, 1997), with some of the physicists involved in these discussions also becoming involved in the econophysics movement.

Now we come to a great curiosity and irony in this matter: some of the main techniques used by econophysicists were initially developed by economists (with many others developed by mathematicians), and some of the ideas associated with economists were developed by physicists. Thus, in a sense, these efforts by physicists resemble a bringing of coals to Newcastle, except that it must be admitted that many economists either forgot or never knew of these issues or methods. This is true of the most canonical of such models, the Pareto distribution (Pareto, 1897).

If there is a single issue that unites the econophysicists it is the insistence that many economic phenomena occur according to distributions that obey scaling laws rather than Gaussian normality. Whether symmetric or skewed, the tails are fatter or longer than they would be if Gaussian, and they appear to be linear in figures with the logarithm of a variable plotted against its cumulative probability distribution. They search for physics processes, most frequently from statistical mechanics, that can generate these non-Gaussian distributions that obey scaling laws.

The canonical (and original) version of such a distribution was discovered by the mathematical economist and sociologist, Vilfredo Pareto, in 1897. Let N be the number of observations of a variable that exceed a value x with A and α positive constants. Then

$$N = Ax^{-\alpha}. \quad (1)$$

This exhibits the scaling property in that

$$\ln(N) = \ln A - \alpha \ln(x). \quad (2)$$

This can be generalized to a more clearly stochastic form by replacing N with the probability that an observation will exceed x . Pareto formulated this to explain the distribution of income and wealth and believed that there was a universally true value for

α that equaled about 1.5. More recent studies (Clementi and Gallegati, 2005) suggest that it is only the upper end of income and wealth distributions that follow such a scaling property, with the lower ends following the lognormal form of the Gaussian distribution that is associated with the random walk, originally argued for the whole of the income distribution by Gibrat (1931).

The random walk and its associated lognormal distribution is the great rival to the Pareto distribution and its relatives in explaining stochastic economic phenomena. It was only few years after Pareto did his work that the random walk was discovered in a Ph.D. thesis about speculative markets by the mathematician Louis Bachelier (1900), five years prior to Einstein using it to model Brownian motion, its first use in physics (Einstein, 1905). Although the Paretian distribution would have its advocates for explaining stochastic price dynamics (Mandelbrot, 1963), the random walk would become the standard model for explaining asset price dynamics for many decades, although it would be asset returns that would be so modeled rather than asset prices themselves directly as Bachelier did originally. As a further irony, it was a physicist, M.F.M. Osborne (1959), who was among the influential advocates of using the random walk to model asset returns. It was the Gaussian random walk that would be assumed to underlie asset price dynamics when such basic financial economics concepts as the Black-Scholes formula would be developed (Black and Scholes, 1973). Letting p be price, R be the return due to a price increase, B be debt, and σ be the standard deviation of the Gaussian distribution, then Osborne characterized the dynamic price process by

$$dp = Rpdt + \sigma p dB. \quad (3)$$

Meanwhile, a variety of efforts were made over a long time by physicists, mathematicians, and economists to model a variety of phenomena using either the Pareto distribution or one of its relatives or generalizations, such as the stable Lévy (1925) distribution, prior to the clear emergence of econophysics. Alfred Lotka (1926) saw scientific discoveries as following this pattern. George Zipf (1941) would see city sizes as doing so. Benoit Mandelbrot (1963) saw cotton prices doing so and was inspired to discover fractal geometry from studying the mathematics of the scaling property (Mandelbrot, 1983, 1997). Ijiri and Simon (1977) saw firm sizes also following this pattern, a result more recently confirmed by Axtell (2001).

Also, economists would move to use statistical mechanics models to study a broader variety of economic dynamics prior to the emergence of econophysics as such. Those doing so included Hans Föllmer (1974), Lawrence Blume (1993), Steven Durlauf (1993), William Brock (1993), Duncan Foley (1994) and Michael Stutzer (1994), with Durlauf (1997) providing an overview of an even broader set of applications. However, by 1993 the econophysicists were fully active even if they had not yet identified themselves with this term.

While little of this work explicitly focuses on generating outcomes consistent with scaling laws, it is certainly reasonable to expect that many of them could. It is true that the more traditional view of efficient markets with all agents possessing full information rational expectations about a single stable equilibrium is not maintained in these models, and therefore the econophysics critique carries some weight. However, many of these models do make assumptions of at least forms of bounded rationality and learning, with the possibility that some agents may even conform to the more traditional assumptions.

Stutzer's (1994) reconciles the maximum entropy formulation of Gibbsian statistical mechanics with a relatively conventional financial economics formulation of the Black-Scholes options formula, based on Arrow-Debreu contingent claims (Arrow, 1974). Brock and Durlauf (2001) formalize heterogeneous agents socially interacting within a utility maximizing, discrete choice framework. Neither of these specifically generates scaling law outcomes, but there is nothing preventing them from doing so potentially.

While some econophysicists seek to integrate their findings with economic theory, as noted above many seek to replace conventional economic theory, seeing it as useless and limited. An irony in this effort is that it has been argued that conventional neoclassical economic theory itself was substantially a result of importing nineteenth century physics conceptions into economics, with not all observers approving of this (Mirowski, 1989). The culmination of this effort is seen by many as being Paul Samuelson's *Foundations of Economic Analysis* (1947), whose undergraduate degree was in physics at the University of Chicago. Samuelson himself noted approvingly that Irving Fisher's 1892 dissertation (1926) was partly supervised by the pioneer of statistical mechanics, J. Willard Gibbs (1902), and as far back as 1801, Nicholas-François Canard (1969) conceived of supply and demand ontologically being contradicting "forces" in a physics sense. So the interplay between economics and physics has been going on for far longer and is considerably more complicated than is usually conceived.

Curiously but unsurprisingly given the tremendous attention given to the new econophysics movement, it has spawned imitators since 2000 in the form of *econochemistry* and *econobiology*, although these have not had nearly the same degree of development. The former term is the title of a course of study established at the

University of Ulm by Barbara Mez-Starke and was used to describe the work of Hartmann and Rössler (1998) at a conference in 2002 in Urbino, Italy (see also Padgett, Lee, and Collier (2003) for a more recent effort). The latter term first appeared in Hens (2002), although McCauley (2004, pp. 196-199) dismisses it as not a worthy competitor for econophysics. Nevertheless, there has long been a tradition among economists of advocating drawing more from biology for inspiration than from physics (Hodgson, 1993), going back at least as far as Alfred Marshall's famous declaration that economics is "a branch of biology broadly interpreted" (Marshall, 1920, p. 637), even as Marshall's actual analytical apparatus arguably drew more from physics than from biology.

In any case, one trend we can expect for some time is for an increase in coauthoring between economists and physicists within the area of econophysics (Lux and Marchesi, 1999; Li and Rosser, 2004). Very likely we shall eventually see the more useful ideas of econophysics coming to be absorbed into economics proper. As that comes to pass, it may also come to pass that the separate and distinct movement we now know as econophysics will cease to exist and will be forgotten, just as most economists do not think about the physics roots of standard neoclassical economic theory today.

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