The Nature and Future of Econophysics

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1 Definitional Issues

In discussing the nature of econophysics, a primary issue must be to understand what it is. This is a rather complicated matter, but attempts at definition have been made. As the neologizers of the term,[1] Rosario Mantegna and H. Eugene Stanley have a distinct authority in this matter. They have proposed the following to 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" [2, pp. viii-ix].

What is most striking about this definition is that it is not an intellectual one primarily, but rather a sociological one. It is based on who is doing the working on economics problems, physicists, not specifically on what those problems are or what the specific methods or theories are that they are using from physics to study or solve these problems. The more usual way to define a "multidisciplinary discipline" (or interdisciplinary or transdisciplinary discipline)[2] is to do so in terms of the ideas that it deals with. Arguably this is the case with such well-established entities as political

[1] See [1, p. 225] for an account of its neologization, with Stanley being specific credit for this innovation at the second Statphys-Kolkata conference in 1995.

[2] It can be argued that "transdisciplinary" might be a better label for econophysics. "Multidisciplinary" suggests distinct disciplines discussing as with an economist and a physicist talking to each other. "Interdisciplinary" suggests a narrow specialty created out of elements of each separate discipline, such as a "water economist" who knows some hydrology and some economics. However, "transdisciplinary" suggests a deeper synthesis of approaches and ideas from the disciplines involved, and is the term favored by the ecological economics for what they are trying to develop.

economy or biophysics. Indeed, this more sociologically oriented definition resembles more the contrast between socio-economics and social economics, which seem to deal with nearly identical ideas and subject matter, but which differ largely in that the former is largely done by sociologists while the latter is largely done by economists.[3]

2 Relations between the Disciplines

Given that econophysics involves in effect physicists doing economics with theories from physics, this raises the question of how the two disciplines relate to each other both ideationally and sociologically. In the realm of ideas it has been traditional to argue that they belong to the distinct categories of physical (or natural or "hard") science and social (or "soft") science. However, this partly elides the question as there are areas of physics that are not so "hard" in that they are not able to be tested experimentally (string theory being a current example), while increasingly one finds the use of experiments in economics, even if these are arguably not as controlled or scientific as most experiments in physics, chemistry, or biology.

Another way to view how they relate is in terms of what parts of the universe they study within the great hierarchy of the structure of reality. As one moves from a micro scale perspective to a macro scale perspective we find physics dealing with the two greatest extremes: nuclear physics at the sub-atomic particle level, and astrophysics at the cosmic and universal level, with string theory arguably attempting to deal with both simultaneously. As one moves up the hierarchy from nuclear physics through greater

[3] This is symbolized by two competing professional associations. The Society for the Advancement of Socio-Economics (SASE) is dominated by sociologists, although there are economists associated with it, while the Association for Social Economics (ASE) is essentially the reverse. The ASE holds meetings in conjunction with the American Economic Association annual meetings, while SASE does not.

levels of aggregation one moves through realms studied respectively by chemistry, molecular biology, organic biology, psychology, economics, political science and sociology, ecology, climatology and geology, and finally to astrophysics as one moves beyond the scale of the planet earth. In this hierarchy we find the social sciences occupying an intermediate scale, with economics providing a crucial link from the behavior of individual people to the behavior of groups of people.

There is also an intellectual hierarchy of the disciplines as well. This generally moves from the more abstract and theoretical to the less so, with pure mathematics at the top, followed by its applied forms (including statistics and computer science), with physics generally coming next, again with the theoretical viewed as above the empirical, then to chemistry (and closely related molecular biology), then on to economics, which has the most mathematical orientation of the social sciences, on through ecology, psychology, and to political science and sociology, even as these latter disciplines have become more mathematical in some of their branches, especially with the application of game theory.

This implicit intellectual superiority of physics over economics opens the door to potential conflicts between the two groups as the project of econophysics has developed and proceeded.[4] Thus we can record prejudices that the two groups entertain regarding each other. On the one hand, econophysicists argue that regular economists are unwilling to accept or deal with data or facts that do not conform to the predictions of their outmoded theories, that in this regard economists are not really scientists. On the other hand, economists who study the same data and models that the econophysicists do have

[4] Recognition of this by economists has led Mirowski [3] to accuse economists of suffering from "physics envy."

been known to complain that the econophysicists are not always aware of the work that the economists have done or the true nature of their theories and that the econophysicists apply models to data without any real theory at all. Arguably, the future development of econophysics will involve the overcoming of these prejudices through communication and mutual research and effort.

3 Problems Being Studied, Methods Being Used

Given that econophysicists work on economic problems with new conceptual approaches from the physical sciences, the issue arises as to what these are. Perhaps the most intensively studied have been the distributions of returns in financial markets [3], [4], [5], [6], [7], [8]. Also studied have been the distribution of income and wealth [9], [10], [11], the distribution of economic shocks and growth rate variations [12], [13], the distribution of firm sizes and growth rates [14], [15], the distribution of city sizes [16], and the distribution of scientific discoveries [17]. Leading models have come from statistical mechanics [18], earthquake models [8], and self-organized criticality models of sandpile avalanche dynamics [19].

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 leptokurtosis rather than Gaussian distributions. A major area of contention regarding this has been in the area of financial returns distributions. The Gaussian theory dates to Bachelier in 1900 [20], who developed the theory of Brownian motion five years before Einstein did in order to model financial

markets. This approach would develop through the mean-variance approach to risk analysis and culminate in such conceptual outcomes as the Black-Scholes formula [21], widely used for the pricing of options and derivatives in financial markets.

The contrasting approach using scaling laws derives from initially from Pareto in 1897 [22], who used it to study income distribution, and was first applied to financial markets by Mandelbrot in 1963 [23]. The Paretian distribution was also used by Lotka [24] to study the pattern of scientific discoveries and by Zipf [25] to study city size distributions, as well as by Ijiri and Simon [26] to study firm size distributions.

4 But Who Preceded Whom?

However, at this point we come to a deeper issue and problem: it is not clear who preceded whom disciplinarily in these developments. Indeed, what we have is a truly complicated muddle of developments. What seem to be models of physics in some cases came from economics, and the much-derided standard models of economics largely came from physics. "Econophysics" may well simply be a new name for something that has been going on for a long time.

Thus, Vilfredo Pareto was an economist and sociologist, even as he preceded the physicists in studying distributions exhibiting scaling laws. Bachelier was a mathematician who studied financial markets, but developed the idea of Brownian motion before the physicists got to it. On the other hand, it was a physicist, Osborne [27], who played a major role in enforcing that standard financial economics would use the Gaussian Brownian motion model.

The role of physicists and physics models as the foundations for the standard neoclassical model that the current econophysicists seek to displace is a much studied story [3]. Canard in 1801 [28] first proposed that supply and demand were ontologically like contradicting physical forces. The founder of general equilibrium theory in economics, Léon Walras [29] was deeply influenced by the physicist Louis Poinsot [30] in his formulation of this central concept.[5] The father of American mathematical economics in its neoclassical form, Irving Fisher [32], was a student of the father of statistical mechanics, J. Willard Gibbs [33]. The culmination of this transfer of essentially nineteenth century physical concepts into standard neoclassical economics came with the publication of Paul Samuelson's *Foundations of Economic Analysis* in 1947 [34], Samuelson himself having originally been an undergraduate physics major at the University of Chicago. Furthermore, even the later, more direct introduction of statistical mechanics applications into economics originally came from economists themselves [35].

Is Econophysics Heterodox?

Clearly econophysics is an ongoing enterprise; whatever it is and whoever is doing it is not going to stop in the near future, whatever its longer term evolution. This raises a more particular question regarding its relationship with the economics profession. In particular, is it something that is acceptable to the mainstream or to orthodox economic theory, or is it something that is outside of this mainstream, something that is heterodox. And if so, will this remain the case?

[5] See [31] for further discussion of this point.

Such a question requires some defining of terms. I shall follow the categorization and set of definitions provided in [36]. These authors argue that there are two aspects involved in understanding useful definitions of these terms, intellectual and sociological, the same two that have been hovering over our discussion already. Thus, they argue that "orthodox" refers purely to an intellectual category. "Orthodox economic theory" is an established and more or less internally consistent set of ideas that have been widely accepted, at least in the recent past. The clearest way to identify this set of ideas is to see what is presented in the most widely used textbooks, with perhaps its purest expression being found in undergraduate textbooks rather than graduate ones, which may be more likely to contain newer cutting edge ideas that may fit less well with this established orthodoxy. Indeed, an important aspect of this orthodoxy is that it is not generally cutting edge or new. It may well be something that is already partially fossilized, something to teach undergraduate students, but not something to be taken too seriously by the most advanced researchers at the cutting edge of the profession.

At this point it should probably be noted that when econophysics sometimes criticize what they consider to be economic theory, it is sometimes this established orthodoxy that is widely publicized, but which is not taken entirely seriously by many advanced economic researchers. Many of them are fully aware of its limitations and problems. This is part of the frustration that some economists have in communicating with some econophysicists.

It should also be noted that even though the established orthodoxy may have a degree of internal consistency, this is likely to be ultimately incomplete. As is well known, some of the most important advances in all sciences come from trying to resolve

unresolved contradictions within normal science theories [37]. The degree to which orthodox economic theory is internally consistent is generally exaggerated when it is taught to students, especially undergraduate students, perhaps to make it simpler for them, if not necessarily for their teachers, although it is undoubtedly the case that some of the teachers believe fully in the consistency or truth of what they are teaching. Nevertheless, it is usually after an orthodoxy (such as "neoclassical economics") has already come to be formed or established that some critic puts a label on it and it comes to appear to be the unified whole that it really is not [38].

"Mainstream" refers to the economics done by those economists who are the dominating figures in the profession, hold professorships at the most prestigious universities and institutes, who edit the most highly ranked journals, who control funding of research at the highest levels, win Nobel Prizes, and so forth. Many critics who are not very well informed believe that this set of people also believe in or strongly advocate the ideas of the most well-known established orthodoxy. Surprisingly this is not always the case, indeed is more likely not to be the case, although they may defend orthodoxy against what they consider to be poorly thought-out or inappropriate attacks or criticisms. There is likely to be a "show me what is better" attitude among the most seriously scientific members of this group, with much less adherence to any particular set of views or theories than many observers think is the case, much more open-mindedness.

Kenneth Arrow is a good example of such a figure, a senior and prominent Nobel Prize winner in economics, he was jointly responsible with Gérard Debreu for one of the centerpieces of established neoclassical orthodoxy, the formal proof of the possible existence of a competitive general economic equilibrium [39]. Nevertheless, in the late

1980s, he was responsible along with the physicists such as Philip Anderson in establishing the Santa Fe Institute, which has been a center of the study of such decidedly non-orthodox ideas as nonlinear complex dynamics and a main center for work on econophysics as well, all of which he has been quite supportive of. Kenneth Arrow is as mainstream as one can get sociologically, but he is no simple defender of established orthodoxy in terms of ideas or research in economics. Other figures who are arguably "mainstream but not orthodox" are interviewed and their work discussed in [36].

Which brings us to "heterodox." In contrast to the previous two, this is seen as being both an intellectual and a sociological category. It is intellectual in being anti-orthodox, or at least non-orthodox. It is also sociologically non-mainstream, its practitioners are outside the dominating group that controls the profession. There is a sense of alienation, even at times persecution, felt within this group. They may feel that their exclusion is due to their papers not being accepted in leading journals due to narrow minded discrimination and unfair exclusion, with the result being their inability to obtain tenure or promotion at good universities or institutes. To the extent that this is tied to ideological factors, such as advocacy of Marxism during various periods, this can add an extra politically vehement element to the sense of alienation and controversy.

Now it must be admitted that there has been such discrimination and rejection of work by some economists who have belonged to certain heterodox schools of economic thought, with Marxists being the most obvious example, and some of these cases are examined and considered in [36]. Efforts at certain universities to purge in a wholesale manner of shut down departments that are controlled by identifiably heterodox economics continue to go on. Curiously, it has been observed that those involved in

these kinds of persecutions and discrimination are frequently second or third tier members of the profession, not its leading lights or most advanced researchers. It is the mediocre who tend to be the enforcers of stale orthodoxy.[6]

It can be noted that on the intellectual side there are various schools of economic heterodoxy that have become established to varying degrees over time, such as Marxism, Austrianism, institutionalism, and others. Many of these schools have themselves created their own sub-orthodoxies and mini-mainstreams, with certain universities, institutes, journals, and even funding sources that favor and support them. Ironically, many of these can be as narrow-minded, or even worse, than the established orthodoxy and mainstream in terms of resisting ideas or researchers who challenge their particular shibboleths.

So, now we can approach answering the question of this section: is econophysics heterodox? At the moment the answer is probably "yes." Certainly it challenges the old established orthodoxy of unique equilibria, rational agents, and normality that one finds in the more simple-minded economics textbooks.[7] It is also the case that as most of its practitioners are almost by definition, and certainly in practice, actually professional physicists, they are outside the dominating mainstream group of economists.

However, the example of Kenneth Arrow and the important role of the Santa Fe Institute, not to mention the past history of physics ideas becoming incorporated deeply into the fabric of the most established of economic orthodoxy suggest, econophysics has a good chance of ceasing to be heterodox, and quite possibly in the reasonably near future. Many serious economists take the research seriously already. More are likely to

[6] In [36], Kenneth Arrow reports that when the then heterodox Marxist economist, Samuel Bowles, was denied tenure at Harvard, the three members of the department who had served as presidents of the American Economic Association (including Arrow) all supported Bowles receiving tenure.
[7] An example of an econophysicist very sharply critiquing established economic orthodoxy is [40].

do so in the future as more economists become more aware of it, especially if it is successful in explaining phenomena that established economic theories have not done well at explaining. It may be quite sometime, if ever, that the ideas of econophysics become fully orthodox. But as more well known and influential economists become involved in joint research with practicing econophysics and it comes to be published in more established journals in economics, it could well enter into the mainstream in the relatively near future, may in fact already be beginning to do so, if still only the "non-orthodox mainstream."

6 The Past as Future

This observer is not going to forecast that there will be ideas developed by economists that will influence physics in the future, although this cannot be ruled out. However, the complicated nature of the interplay between economics and physics that has transpired in the past seems very likely to be a model for the future. This complicated interplay replicates a broader pattern of developments as various disciplines are influencing each other through complexity theory and other multi or transdisciplinary ideas. The interactions between physicists and economists that have happened at the Santa Fe Institute echo earlier such interactions at institutes in Brussels and Stuttgart. Furthermore, the interactions are not only between economists and physicists but between biologists and both of them as well as some other disciplines.

While physics has probably had the more dominating effect on the development of formal economic theory, a subtext throughout the last two centuries has been a competing strain of interaction between economics and biology, especially evolutionary theory [41]. Alfred Marshall, the main expositor of neoclassical economics in the

English language tradition, famously argued [42, Preface] that "biology is the Mecca of economics," even as he codified the earlier mathematical developments drawn from physics in his formal apparatus. This reflected the great influence on Marshall of Darwin. However, earlier Darwin himself had been crucially influenced by the economist Malthus, whose theory of population was a crucial inspiration for Darwin in developing his theory of natural selection. Even so, the lack of a formal mathematical theory of evolution during this earlier period pushed the more biological approach aside, leaving it to the institutionalists [43] and others to apply it in economics until more recently.

However, at the Santa Fe Institute and other places, modern evolutionists have become students of nonlinear complex dynamics and game theory and other more mathematically sophisticated approaches [44], partly as a result of interacting with both physicists and economics. Robert May, a biologist with a physics background played a crucial role in suggesting the application of chaos theory to economics [45].[8] The appearance of ecological economics and its enormous increase in influence in a relatively short time is an indicator of what is going on [47].

Thus we should expect that econophysics will continue to develop and to increase in influence. However, in the longer term, as economists become aware of these ideas and come to accept them, and physicists learn more about what has been done by economists, we may find that the ultimate success of econophysics will end in its

[8] The neologizing of "econophysics" has since inspired the neologizing of both "econochemistry" and "econobiology," although clearly the latter has been going on already for a long time in practice. In a lecture at Urbino in 2002, Rosser identified a paper by Hartmann and Rössler [46] as a possible example of econochemistry. Of course, Rössler is a physical chemist, much like the late Ilya Prigogine of Brussels.

disappearance, just as the earlier movement of physics ideas into economics occurred so successfully that most are not even aware of what happened anymore.

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