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Worrying trends in econophysics

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Abstract

Econophysics has already made a number of important empirical contributions to our understanding of the social and economic world. These fall mainly into the areas of finance and industrial economics, where in each case there is a large amount of reasonably well-defined data.

More recently, Econophysics has also begun to tackle other areas of economics where data is much more sparse and much less reliable. In addition, econophysicists have attempted to apply the theoretical approach of statistical physics to try to understand empirical findings.

Our concerns are fourfold. First, a lack of awareness of work that has been done within economics itself. Second, resistance to more rigorous and robust statistical methodology. Third, the belief that universal empirical regularities can be found in many areas of economic activity. Fourth, the theoretical models which are being used to explain empirical phenomena.

The latter point is of particular concern. Essentially, the models are based upon models of statistical physics in which energy is conserved in exchange processes. There are examples in economics where the principle of conservation may be a reasonable approximation to reality, such as primitive hunter–gatherer societies. But in the industrialised capitalist economies, income is most definitely not conserved. The process of production and not exchange is responsible for this. Models, which focus purely on exchange and not on production cannot by definition offer a realistic description of the generation of income in the capitalist, industrialised economies.

Keywords: ■; ■; ■; ■

1. Introduction

Econophysics has already made a number of important empirical contributions to our understanding of the social and economic world. Many of these were anticipated in two truly remarkable papers written in 1955 by Simon [1] and in 1963 by Mandelbrot [2], the latter in a leading economic journal.

The main area of activity for econophysics has been financial markets, a natural area for physicists to investigate given its terabytes of well defined and finely grained time series data. The evidence for the fat-tailed

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distribution of asset price changes noted in Ref. [2] has now been established beyond doubt as a truly universal feature of financial markets. A genuinely original and very important contribution of econophysics, using the technique of random matrix theory, has been the discovery that the empirical correlation matrix of price changes of different assets or classes of assets is very poorly determined (e.g. [3–6]). This latter point undermines Markowitz portfolio theory and the capital asset pricing model, still regarded as powerful and valid theories by many economists (e.g. [7]). There have been very few extensions of the random matrix approach outside financial markets, though there are many potential applications. Ref. [8] for example uses the technique to investigate the convergence of business cycles in the main European economies.

Another active area of empirical investigation for econophysics has been industrial structure and its evolution. As with financial markets, large amounts of generally reliable data are available in this area, too. It should be said that some of the econophysics literature is perhaps less original and/or well established than physicists might appreciate. Decisive evidence on the right-skew distribution of firm sizes, for example, has been both available and well known in industrial economics for many years (e.g. [9,10]). Plausible candidates in the economics literature to represent the empirical size distribution are the lognormal, the Pareto and the Yule. The main problem is in capturing the coverage of small firms. Recent attempts to do this, such as [11] on the population of US firms, lend support to a power-law distribution linking firm sizes probability densities with the size ranking of firms. However, this may well be an as yet unexplained outcome of aggregation, because the findings seem not be robust with respect to sectoral disaggregation [12]. A more decisive finding by econophysicists is that the variance of firm growth rates falls as firm size increases, although this too was anticipated in the early 1960s [13]. A further discovery is that the size–frequency relationship, which describes the pattern of firm extinctions, appears to be very similar to that which describes biological extinctions in the fossil record [14,15].

Despite the qualifications in the above, there is no doubt that the open-minded approach of econophysics in investigating empirical regularities in social and economic systems has enhanced knowledge and should be welcomed unequivocally by economists.

2. Areas of concern

Econophysics has begun to tackle other areas of economics where data is much more sparse and much less reliable. In addition, econophysicists have attempted to apply the theoretical approach of statistical physics to try to understand empirical findings.

Our concerns about developments within econophysics arise in four ways:

- a lack of awareness of work which has been done within economics itself,
- resistance to more rigorous and robust statistical methodology,
- the belief that universal empirical regularities can be found in many areas of economic activity,
- the theoretical models which are being used to explain empirical phenomena.

The first point can be dealt with briefly, but is nevertheless important. The authors of the present article are economists who are critical of much of the mainstream work in economics. But economics is not at all an empty box and has made progress in understanding how the social and economic worlds operate. Much of the econophysics literature shows no recognition of what has been done within economics. One of the present authors has drawn the analogy of imagining 'a new paper on quantum physics with no reference to received literature' [16]. One weakness, which arises from this is the belief that empirical findings may be original, whereas they, or ones which are very similar, already exist in the economics literature. We have referred to some examples in Section 1 above. A more serious weakness is that this may lead to theoretical models which are quite inappropriate to the problem being addressed, a point to which we return below.

An active area of enquiry, both empirically and theoretically, is the distribution of income and wealth [for example the papers in Ref. 17], and we use this below as a practical illustration of our concerns about the other three points.

3. Empirical regularities in the distribution of income (and wealth)

Many recent papers in econophysics have sought to characterise the distribution of income by a mixture of known statistical distributions. Even within this literature, there is a dispute about what these distributions are. The upper end of the distribution is believed to be characterised by a power law, as Pareto [18] argued over 100 years ago. The argument is about the bulk of the income, held by over 95 per cent of the population. Ref. [19] cites papers, which claim that this is exponential, and papers, which claim it is lognormal. The authors of Ref. [19] itself incline to support the lognormal, but note that the distribution itself shifts over time, even over the 20 year period which is analysed.

It does not seem to be appreciated that the data is sufficiently inexact as to not really permit an unequivocal characterisation, even for a single data set. This is particularly the case when the data, as is often the case with income and wealth data, is binned into ranges of values.

Certainly, the attempt to achieve an exact characterisation of income distribution has not really been an active area of research in economics for at least 30 years [20], because of points such as these. A recent exception [21] develops the generalised beta and quadratic elasticity probability density functions to try to characterise US income distribution. The generalized beta distribution nests the generalized beta of the first and second kind, generalised gamma, lognormal and Pareto and also introduces a number of new distributions to the literature. The quadratic elasticity distribution provides another generalisation of the gamma distribution.

It is easy to generate hypothetical data sets which, when binned, can give misleading pictures of the statistical distributions which characterise them. Ref. [22] shows that data generated from a lognormal distribution can be easily misinterpreted as evidence of power laws. Without selecting specific examples, we have to say that in our view a number (though by no means all) of recent papers by econophysicists 'validating' their theoretical model by reference to empirical data are really no better empirically than this hypothetical example constructed to show the dangers of trying to obtain exact characterisations of much economic data.

The focus on visual tools of inspection and visually interpretable estimation procedures (i.e., graphical power-law fits) in the econophysics literature has certainly brought about a number of important new insights not revealed before by the battery of refined econometric tests applied by economic researchers. However, despite the new perspectives sometimes gained in this way, there is no reason to confine oneself to log regressions and stop short of a more rigorous examination of empirical data after the initial stage of exploratory data analysis. It seems worthwhile to point out that estimation of Pareto laws via the usual log regression is necessarily inferior to other techniques (as it misuses linear regression by applying it to strongly dependent data) and a wealth of more rigorous procedures have been provided for this purpose in the statistics literature (for example Ref. [23] gives an overview).

The initial excitement and later disappointment about market crash prediction via detection of log-periodic precursors might serve as a telling example of how easily researchers can be misled into self-deception by a combination of data-mining and apparently good visual fits without a more rigorous statistical analysis and an explicit *test* of a well-defined hypothesis . The econometrically trained observer can hardly be blamed for feeling appalled by the hype made around a pretended law whose statistical basis is unclear, and whose claimed evidence had never been replicated by researchers outside a small circle of adherents. Despite this weak basis, the 'log-periodic' business had been exaggerated into doomsday speculations published in serious journals (e.g. [24]), although not even its prophecies for the mundane world of the stock markets had ever been scrutinized in a rigorous fashion.

It might also be emphasized that there is no reason to believe that one *should* find simple power laws in *all* types of socio–economic data that are universal over countries and time horizons. Although their interpretation of power laws as signatures of complex, possibly self-organizing systems makes them a much wanted object, one should be careful in not seeing a power-law decline in each and every collection of data points with a negative slope. In fact, the ubiquitous declaration of studied objects as fractal or self-similar has been criticized also in a paper [25] which surveyed all 96 papers in *Physical Review* journals over the period 1990–96 which contain an empirical scaling analysis of some natural or experimental time series. They find that "the scaling range of experimentally declared fractality is extremely limited, centered around 1.3 orders of magnitudes'' while a true self-similar or fractal object in the mathematical sense requires infinitely many orders of power-law scaling. They find it doubtful to claim that all these studies with their typically rather small range of scaling behaviour show that 'the geometry of nature is fractal.'

In economics, it is also important to realise that key relationships might *change over time*. For example, there is an important conjecture in economics by one of the first Nobel laureates that the distribution of income and wealth vary markedly over time. This is the so-called Kuznets hypothesis [26], which postulates that during the process of industrial development, income inequality first rises markedly and then narrows, following an inverted U shape. There are good reasons as to why this might be the case. For example, as per capita income rises, education becomes more widely available throughout the population, increasing the human capital of an increasing proportion of the population. Further, there is a long-run shift from the relatively low productivity sector of agriculture into the higher ones of manufacturing and services.

There is a large literature on the Kuznets hypothesis, which even to date is not conclusive. For example, a generally held view on US wealth distribution is that inequality was low in the colonial period, rising sharply in the period to 1840, reaching a peak sometime between 1870 and 1920, then declining markedly through to the 1970s. But Ref. [27], for example, argues that the evidence is much less clear-cut.

However, all the literature shows that there are large changes in the distribution of income and wealth over long periods of time. Theories which do not take this into account are at best partial.

4. Theoretical models of the distribution of income and wealth

There is a general (and understandable) tendency on the part of econophysicists to develop theoretical models, which are based on the principles of statistical physics. We obviously recognise that all theories are approximations to reality. In certain specific economic applications, models constructed on this basis may very well be valid. But in general this is most definitely not be the case, and models constructed on these principles ignore absolutely fundamental features of economic reality. Any congruence obtained with the data by such models is therefore spurious.

The main problems with translating statistical physics models into economics are

(1) these are essentially exchange-only models of economic and financial processes, which take no account of production,
(2) they often lead to a confusion of basic concepts, in particular the concepts of transactions and of income.

One of the most successful econophysics models is the Minority Game (MG) (e.g. [28]). The MG was itself based on the El Farol Bar Problem originally developed by the unconventional economist Brian Arthur [29]. The El Farol model explored the dynamics of attendance at an Irish music venue where attendance was only enjoyable if less than half the fans turned up. The concept was then applied by analogy as a model of stock market behaviour, on the principle that, in general, those who win out of stock market exchanges are in the minority.

The model has succeeded in the sense that its dynamics mirror some of the stylised facts that characterise stock market data. But it is also a parsimonious model. No claim is made by its developers that the underlying dynamics of the Stock Market are those of a MG. This is in contrast to the standard models of physics where, epistemological fineries aside, most practitioners believe their models are not parsimonious but, to the best of our knowledge, actual descriptions of the forces and interactions at hand.

There is an essential way in which the MG, as normally described, is an approximation to the underlying model of the stock market. In most MG implementations, the number and/or composition of positions is constant. In reality, the number and composition of shares on the stock market is not constant. However, as an approximation to reality, the assumption of a constant number is not too unreasonable.

But this is certainly not the case with income. A striking feature of the total income of an industrialised economy is that, even after allowing for inflation and population growth, it expands dramatically over time. So, for example, in 2005 per capita income in the US economy is around 150 per cent larger than in 1955. If we allow for population growth the increase is over 400 per cent. Over a longer period, the expansion is even more marked. From 1820 to 2005, for example, real per capita income in the US rose by over 2000 per cent, and real income in total by some 7000 per cent.

The industrialised economies of the West, and increasingly of Asia, are emphatically not a conservative system: income is not, like energy in physics, conserved by economic processes. Therefore, it is a fundamental fallacy to base economic models on a principle of conservation. Yet this is an inevitable consequence of exchange-only models, since exchange *is* a conservative process.

There is a fundamental distinction between transactions and income. Transactions are a key economic process, and they are necessarily conservative processes. When you go and buy a cup of coffee, the transaction involves your money balance falling by the price of the coffee, and the cafe owner's money balance rising by the identical amount.

The apparent paradox that a key economic process is conservative, but industrialised economies themselves are not, is resolved by making production, and not exchange, the core economic process. Capitalist economies are, as already been noted, characterised by economic growth. And growth occurs because production produces a net physical surplus: the quantity of goods produced exceeds the inputs consumed in their production. An economic analysis of this was provided by Sraffa in Ref. [30], though economists have since failed to develop it sufficiently as a dynamic model.

Models, which focus purely on exchange and not on production cannot by definition offer a realistic description of the generation of income in the capitalist, industrialised economies. There are many examples of human societies where models, which omit the process of production, and assume that the total amount of income is conserved, may nevertheless be reasonable approximations to reality: primitive hunter–gather societies, for example, or modern on-line poker tournaments. But the same simplification cannot be applied to the industrialised economies as a whole.

Another perspective on the same point is provided by Refs. [16,31]. Both these authors note that modern economics goes back to Adam Smith in 1776. And one of Smith's most important contributions is that bilateral exchange between agents is usually advantageous to both. Economists in the 18th century and before used to think that economic processes conserved income, but Smith, and shortly after him Ricardo [32], reversed this view.

All this is not to say that economics has satisfactory theories of either growth or the distribution of income. Refs. [33,34], for example explained as long ago as the 1930s why technological change is such distinguishing feature of capitalism. However, none of these intuitions have been sufficiently developed to constitute a theory by the standards of physics.

But econophysicists will not offer any real way forward for economics if they restrict their attention to exchange-only models.

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