Eur. Phys. J. Special Topics 225, 3281–3291 (2016)

DOI: 10.1140/epjst/e2016-60126-7

THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

Regular Article

Ten years after "Worrying trends in econophysics": developments and current challenges

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Received 19 April 2016 / Received in final form 15 September 2016
Published online 22 December 2016

Abstract. Econophysics has made a number of important additions to scientific knowledge. Yet it continues to lack influence with both economists and policy makers. Ten years ago, I and three other economists sympathetic to econophysics wrote a paper on worrying trends within the discipline. For example, its lack of awareness of the economics literature, and shortfalls in the use of statistical analysis. These continue to be obstacles to wider acceptance by economists. Like all agents, policy makers respond to incentives, and economists understand this very well. Much of the econophysics community appears to think that simply doing good science is sufficient to have the work recognised, rather than relating to the motivations and incentives of policy makers. Nevertheless, econophysics now has three major opportunities to advance knowledge in areas where policy makers perceive weaknesses in what they are presented with by economists. All can benefit from the analysis of Big Data. The first is a core model of agent behaviour which is more relevant to cyber society than the rational agent model of economics. Second, extending our understanding of the business cycle, primarily by incorporating the importance of networks into models. Third, devising proper measures of output in cyber society.

1 Introduction

1.1 Overview

I became actively involved with the econophysics community, along with like minded economists such as Steve Keen, Mauro Gallegati and Thomas Lux in the late 1990s. By the mid-2000s, we continued to acknowledge both the actual and potential value of econophysics.

But we had developed concerns, and after the World Econophysics conference in Canberra in 2005, the four of us published a paper entitled "Worrying trends in econophysics" [1].

So this is a timely opportunity to reflect upon econophysics and economics 10 years on. The invitation from the editors to write a paper for this volume began with a

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request that the contributions should take the form of "an introspective assessment by practitioners in the field [of econophysics]". The potential authors were further asked to "stress what they think are the main issues in rebuilding the science of economics". Those contributors who are themselves economists were specifically enjoined to write critiques of the "endeavour" of econophysics, and to describe how it can contribute to the understanding of economic systems.

I am in a number of ways critical of econophysics. This is not so much in respect of the scientific findings of the community. Rather, it is the lack of awareness of what drives both economists and policy makers, how the community might learn to relate to these groups better.

The substantive positive contribution of this paper is to set out three major challenges, each a very difficult problem, which I believe that econophysicists, working in conjunction with sympathetic economists, are very well placed to address.

1.2 How I came to be involved in econophysics

With these themes in mind, some background information about my own interactions with econophysics might be helpful. I started my career as a macroeconomic forecaster for a research institute in London, the National Institute of Economic and Social Research. We ran a large model of the UK economy, based upon equations estimated on time series data using econometric techniques.

It was during this time that my first doubts about economics began to arise. A great advantage of being a forecaster is that your model is confronted with new data over time. You make a prediction today for the next year, say, and actual data over this period is then published in the official national accounts. The performance of your equations on genuine out of sample data therefore comes under constant scrutiny. In contrast, an econometric equation published in an academic journal, unless it becomes one of the very few to be highly cited, is rarely, if ever, subject to the scrutiny of genuine out of sample performance. I say it was an advantage being a forecaster, but this is where the problems arose. The equations broke down much more frequently and by much more substantial amounts, than econometric theory suggested. At the time, it was a real puzzle, and I became disillusioned with economic forecasting.

My concerns about economics became more general, and in 1994 I published a book *The Death of Economics* [2]. It sold well over 1 million copies worldwide. A title which reflected more accurately the contents would have been something like *A Theoretical and Empirical Critique of General Equilibrium Theory and Free Market Policies*. But somehow, I doubt it would have been as successful.

I had been interested for some time in different approaches and worked, for example, on expert systems, as they then were, and neural networks [3,4]. But after initial enthusiasm, none of these alternatives, at the time, seemed satisfactory.

1.3 The initial excitement of econophysics

It was in the late 1990s that I came across the work of econophysicists such as Gene Stanley, Jean-Phillipe Bouchaud and Rosario Mantegna. This was far more exciting. Economics is essentially a theory about how individual agents make decisions. Here was an approach which had such a theory. It was completely different from rational choice in economics, where agents select in the basis of the attributes of alternatives. In the model imported from statistical physics, agents paid no attention to such attributes. Instead, their decisions were based on social influence, on the decisions made by other agents.

Within economics itself, some famous names, including Keynes, had suggested that social influence was important in the decision making of agents, though this theme has never been absorbed into the mainstream. Perhaps the only formal articulation of this was the theory of what we now call preferential attachment, published by Herb Simon as long ago as 1955 [5], and rediscovered independently in the late 1990s by Barabasi [6].

So econophysics had a model of agent behaviour. It was one which, in terms of the implied level of agent cognition, was at the complete opposite end of the spectrum to that of the rational choice theory of economics. And it had some powerful empirical findings, such as the power law distribution of firm sizes, the fat tails in the distribution of asset price changes, and the empirical indeterminacy of the cross-correlation matrix of such changes, revealed by the application of random matrix theory. What more was there to like?

In fact, one of my first publications using the approaches of econophysics helped me to understand my long-held conundrum about why macroeconomic forecasts were so bad. With Craig Mounfield, who had just completed his PhD in statistical physics at Cambridge, I used random matrix theory to show that key macroeconomic time series, such as GDP, were dominated by noise rather than by signal [7].

1.4 Emergent concerns

In [1], we identified four areas of concern: "First, a lack of awareness of work that has been done within economics itself. Second, a 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" (p. 1).

I believe that each of these points continues to merit consideration by econophysicists. Anyone interested in them can readily consult the original paper, so there is no point in going into them in detail here. I do, however, make reference to them in the next section.

2 Why has econophysics had little impact on either economics or policy?

2.1 An illustrative example

By 2000, econophysicists had established scientifically beyond reasonable doubt that:

- the statistical distribution of asset price changes was fat tailed;
- the empirical correlation matrix of asset price changes, whether of asset classes or of individual assets, was poorly determined.

These were powerful results, which from a purely scientific perspective demanded to be taken note of. However, in the run up to the financial crisis of the late 2000s, both economists and policy makers essentially paid no attention to these findings. They continued to rely upon Value at Risk models which assumed a Gaussian distribution of asset price changes. And they continued to rely upon the Capital Asset Pricing Model for assessing the risk on portfolios, which is undermined by the results on the empirical correlation matrix obtained by random matrix theory.

It would be going too far to claim that if these findings had become widely accepted and integrated into risk assessment processes, the financial crisis would have been avoided. But, undoubtedly, both financial institutions and policy makers in central banks, finance ministries and international bodies would have been better equipped to understand the level of risk in the financial system.

Why was the science ignored? This is a wide ranging question, which could easily be the subject of an entire book. So the discussion will inevitably be compressed and is not intended to be completely definitive.

2.2 Policy makers and their incentives

Over the past 20 years, I have worked closely with my colleague Bridget Rosewell. She has held a number of high profile policy positions. She was Chief Economic Advisor to the Mayor of London, for example, and was recently appointed by the Chancellor of the Exchequer (the finance minister in the UK) to the influential Infrastructure Commission. She is a non-executive director of several large UK companies. Together, we have written several papers over the years on the interface between scientific advance and policy. Our focus has been on agent based modelling and complexity science, but our arguments apply equally well to econophysics, which in any case can be seen as forming part of these two categories of science.

The great insight of economics is that agents react to incentives. This does not necessarily imply that they react exactly in the way described by rational choice theory in economics. But if the set of incentives faced by agents changes, some agents will change their decisions. Policy makers are no different. They, too, are influenced by incentives, a point which non-economists often fail to appreciate.

In [8], for example, we state that “It is essential for modellers to understand that innovation in policy analysis usually arises from the need to support a policy preference or choice. Decision makers themselves are not in general interested in the science which underlies the modelling”. In other words, if an existing methodology appears to be useful to policy makers, and also appears to have underlying scientific backing, a policy maker has little incentive to take advice from those who use a different methodology, even if it is scientifically superior. The advice which he or she is receiving appears satisfactory.

When an existing approach either does not give answers acceptable to the policy maker or is not helpful, an opportunity exists for a new approach to establish credibility. A current illustration is the work on networks and the interconnections between financial institutions [for example, 9]. Mainstream economic models took no account of the network structure, a feature which was so important during the financial crisis. But before the crash, policy makers believed that the existing VAR and CAPM models gave them answers which were useful.

2.3 Why economics occupies a powerful position

The power of economics in policy making is in part due to the fact that economists have a good understanding of the incentives which motivate policy makers. It is worth quoting at some length from [8] “Economics has authority simply *because* it has authority, and has had authority for decades. Decision makers, who in general are *not* experts in any particular discipline, are often predisposed to consider the recommendations based on economic models favourably. They are tried and trusted. Further, economists have the advantage in that they often purport to give *the* answer. Economics, over the course of a century or more, has honed and refined its methodological and epistemological approaches to the analysis of practical questions. This does not mean that it correct. But because of this process within the subject, there is much more agreement amongst economists than is commonly supposed. So, for example, different teams of economists might disagree on the impact of, say, a road pricing proposal. But they will agree on how conceptually the problem should be approached".

There are many criticisms of orthodox economics, and I myself have been critical in various ways for a long time [for example, 2, 10, 11, 12]. But it is crucial to grasp two things. First, it is not an empty box. Second, the discipline has made important progress in some respects, particularly over the past twenty years.

2.4 Progress in economics

Economics is essentially a theory of how individual agents[1] make decisions. In the jargon of economics, it is concerned with micro-economics. The discipline of macro economics exists separately, and is certainly influential. But in the mainstream, at least, models of how the economy behaves at the macro, or aggregate, level are required to be based upon micro level theoretical foundations. The seminal work was the so-called real business cycle models by Kydland and Prescott in the 1980s [13], for which the scholars received the Nobel Prize in 2004. The more modern versions of these models have the exotic description of Dynamic Stochastic General Equilibrium (DSGE).

It is the area of micro-economics where economics has made distinct progress. Compared to the mid-1990s, the contents of leading journals are much more heavily empirical. There are two reasons for this, which I discuss in [14]. Behavioural economics has become much more widely accepted. This involves observing how agents actually do behave in specific situations, and comparing their behaviour to the predictions of the rational choice model. For example, it is increasingly accepted that the efficient markets hypothesis (in its various forms) is violated. One reason, for example, is systematic over-confidence (e.g. the papers in the symposium on overconfidence in the Fall 2015 issue of the *Journal of Economic Perspectives* such as [15].

In addition, there has been a parallel rise of powerful technical advances in the econometric analysis of large scale cross-section and longitudinal data bases. One development in particular is that of correcting for self-selection in participating in different kinds of policy programmes. This has opened up the way to the much more effective empirical evaluation of such programmes. For example, suppose prisoners who take up the opportunity to learn a skill, say, show lower rates of re-offending once released. Is it the skill itself which causes this, or is it the possibility that those who volunteer for such programmes have a higher propensity to not re-offend for other reasons?

2.5 Econophysics and economists

Most econophysicists are not economists. But the first of the worries we expressed in the 2006 paper cited above was a lack of awareness amongst the community of the literature in economics. It would be going too far to say that economics is about to abandon its core model of rational choice theory, but things have moved forward. Economists are only too willing to dismiss criticisms or alternative approaches which do not show familiarity with developments in economics. They may sometimes go too far in this, but as a general principle it seems to be perfectly reasonable. It is not

[1] An agent in this context can mean not just a person, but a firm, a government, an international body, depending upon the context.

just econophysics but the other social sciences which often continue to maintain a caricature of economics, rather than take into account how the subject has changed. This is not a good strategy for persuading economists to take you seriously.

The second of the worries, relating to statistical techniques, also remains relevant. Economists are well trained in statistical analysis and are quick to dismiss discussions which they do not think meet appropriate standards. There are many papers, for example, in econophysics which claim to demonstrate the existence of a power law. But whilst the distribution in such cases is highly non-Gaussian, it is often obvious purely by visual inspection that the data follow a different distribution than a power law. Even worse, econophysics papers sometimes attempt to fit different power laws to different parts of the overall distribution. Economists would instinctively try and describe the entire distribution. I believe that this kind of work has alienated, and continues to alienate, economists who might otherwise be sympathetic, or at least not dismissive of, the ideas and results of econophysics.

The fourth of the "worries" was the theoretical models being used to explain behaviour. This has become even more salient given the developments within micro economics. But it is this "worry" which gives the opportunity to change the tone of this article and to look forward in a positive way to how econophysics can help to solve one of the outstanding grand challenges in economics.

3 Three major challenges (1)

3.1 The core model of rational behaviour

All theories make simplifying assumptions in order to explain reality. The key assumptions of the fundamental model of economics are as follows. Each agent has a set of tastes and preferences which are fixed. These tastes and preferences are independent of the decisions of other agents. The agent, when choosing between alternatives in any given situation, gathers all available information on the agents. The agent has the cognitive capacity to process this information, and compare the attributes of the alternatives to his or her preferences. Subject to constraints such as income, the agent then makes the best possible (the optimal) decision.

These assumptions have been relaxed in two main ways over the past few decades. Following the seminal works of George Akerlof and Joe Stiglitz [for example 16, 17], economists now usually assume that agents have incomplete information. The amount of information may vary across agents, the situation of so-called asymmetric information. Agents still optimise, and all the other assumptions remain in place, but incomplete rather than complete information obviously widens the range of situations in which the assumptions are a reasonable approximation to reality. The second relaxation is essentially to recognise that there are costs involved in both gathering and processing information. Particularly in situations in which agents face many alternatives, an agent may only gather and process information on a small number, until a satisfactory one is discovered, one which is reasonably close to the preferences of the agent, who forms the view that the costs of further search outweigh the potential benefits of making a choice which matches preferences even more closely.

It is easy to poke fun at this theory, but it is by no means an empty box. In mature consumer markets, for example, where agents are familiar with the different brands and their different attributes, it is a powerful tool for understanding actual decisions.

3.2 The challenge: what is rational behaviour in cyber society?

The real challenge is to understand the behaviour of agents in cyber society. Even before the very recent literal explosion in the amount of information created on a daily basis in cyber, the market-oriented economies of the West had already created a stupendous cornucopia of choice. Eric Beinhocker in his book *The Origin of Wealth* [18] considered the choices available in New York City alone "The number of economic choices the average New Yorker has is staggering. The Wal-Mart near JFK Airport has over 100,000 different items in stock, there are over 200 television channels offered on cable TV, Barnes & Noble lists over 8 million titles, the local supermarket has 275 varieties of breakfast cereal, the typical department store offers 150 types of lipstick, and there are over 50,000 restaurants in New York City". At the stock keeping unit level (SKU), the level at which retailers place orders, he states "The number of SKUs in the New Yorker's economy is not precisely known, but using a variety of data sources, I very roughly estimate that it is on the order of tens of billions".

The great polymath Herb Simon over sixty years ago expressed serious doubts about the ability of agents to gather and process information in the way implied by rational choice theory. In his seminal paper on behavioural economics [19], he wrote "[T]he task is to replace the global rationality of economic man with a kind of rational behavior which is compatible with the access to information and computational capacities that are actually possessed by organisms, including man, in the kinds of environments in which such organisms exist".

As mentioned above, economists have incorporated the concept of the costs of gathering and processing information into their theory of rational choice. Agents search amongst alternatives until they find one which is optimal, once they take into account these information costs. Economists describe this decision rule as "satisficing". In fact it was Simon who introduced this phrase in 1955, but his meaning was fundamentally different. Simon argued that in many situations, the concept of optimisation made no practical sense. Even ex post it might very well be impossible to identify what the optimal decision would have been. Instead of trying to optimise, agents should choose a heuristic decision rule which, for a period at least, gives satisfactory results. Economists have completely altered Simon's original meaning of satisficing, which of course challenges the basic principle of optimisation.

The most important challenge in economics is to construct "null models" of agent behaviour which are applicable to the increasing number of circumstances in which the conventional model of rational choice is no longer valid. By "null", we mean the basic model, which can be adapted as required to particular situations. Simon believed that agents use rules of thumb, heuristics, as decision making rules. But it is not very helpful to try and construct a plethora of different rules, each unique to its context. We need some basic principles, which can then be "tweaked" as required.

Econophysics essentially imports as its "null" model the particle model from statistical physics. The behaviour of an agent is completely governed by its interaction with other agents. Its tastes and preferences, starting to translate the model into the language of economics, are not fixed, but are altered by interactions with others. In complete contrast to the cognitive demands of the rational agent model, this agent has zero intelligence.

This model does have initial plausibility in considering agent behaviour in cyber space. The vast plethora of choices means that it could be very sensible simply to be guided by the decisions of other agents. An important articulation of this principle is of course that of preferential attachment.

A powerful extension of this principle is a behavioural model developed within cultural evolution theory. Most of the time agents choose by copying from the choices made by agents who have already made their selections, but occasionally the choice is based on a type of random selection. The model has had considerable application in anthropology and cultural evolution, where it is often referred to as the "neutral" model of selection. In other words, when agents select between alternatives, they are "neutral" with respect to their attributes. Examples include [20–24].

In models of this kind, the structure of the connections between agents – who influence whom – is obviously very important. Yet in their basic form, they essentially assume that agents take into account the decisions of all other agents. So two central challenges for econophysicists are:

- to develop cultural evolution theory so that it incorporates not just networks with fixed topology, but ones in which the structure also evolves;
- to identify in specific applications, using Big Data and advance computational techniques, the relevant network, and to calibrate these models against the data.

4 Three major challenges (2)

4.1 Networks and macroeconomics

Economists are beginning to appreciate the potential importance of networks. For example, one of the 2014 issues of the leading American Economic Association journal the *Journal of Economic Perspectives* carried a symposium of papers on the topic [for example, 25]. This is an area where econophysicists can attempt to make common cause with economists.

Networks are a crucial feature of the macro economy. In contrast to micro economics, macro has made very little progress in recent decades, and has arguably gone backwards. The equilibrium paradigm has been imported into macro, more precisely into the micro foundations of macro in ways which even a fair number of mainstream economists feel is implausible. The only way in which DSGE models are able to generate business cycles is essentially by building in more and more "imperfections" to the otherwise unimpeded functioning of markets, in ways reminiscent of the epicycle of Ptolemaic astronomy.

There is a great opportunity for econophysicists in the area of macroeconomics. The mainstream models are felt to be unsatisfactory, both by policy makers and even by mainstream economists. In the late 2000s, the world economy experienced the only truly global recession since the early 1930s, though its impact was nowhere near as severe as the latter, the so-called Great Recession.

4.2 The business cycle

Econophysicists have in general showed little interest in modelling what economists describe as the business cycle. This is the persistent fluctuations in the growth rate of real output (GDP) which have been observed from the very beginnings of capitalism in the late 18^{th} century. They are a fundamental feature of the developed market-oriented economies, yet economics lacks a satisfactory explanation.

As an aside, the phrase "business cycle" needs perhaps a couple of sentences in an econophysics journal. Almost invariably, when I have shown a time series plot of, say, annual real GDP growth rates in America to a group of econophysicists and described it as the business cycle, there has been polite laughter. The data do not show the regularities of a cycle in physics. But the phrase is part of the jargon of economics. We speak of the 'business cycle, not because we believe it follows the regularities of, say, a sine wave, but because within any single economy, there is strong cross-correlation of output growth across its various industries. In the upswing, most industries do well, and most do badly during recessions. Although there can be shocks to individual industries, the fact that they tend to move together strongly suggests that there are general causes at work, rather then ones specific to individual sectors.

Over a decade ago, I published a simple theoretical model in *Physica A* [26] in which the business cycle was driven purely by the percolation of sentiment about the future across firms with power law distributions of their sizes. Although very simple, the model could replicate key underlying features of the cycle [27 for a detailed empirical description].

Much more sophisticated versions could be developed, which also incorporate monetary features. The idea that the cycle is driven by business psychology, by sentiment, is a key theme of Keynes' *General Theory*. Econophysics is already having an impact on macro by its models of cascades across networks of financial institutions, and there is a great opportunity to attack a really hard and crucially important area in economics. Analysing Big Data in ways which are guided by theoretical principles, rather than by a purely data driven approach, offer an exciting way forward.

One reason I suspect that econophysics has paid little attention to macroeconomics is that, unlike say financial markets or data on firms, the data sets are short and noisy. But that it all we have. Capitalism did not start until 250 years ago (at most), so it just not possible to generate a large number of observations of time series data on real GDP growth.

5 Three major challenges (3)

5.1 Valuing output in cyber society

This brings me to a final challenge, which I discuss briefly. The measurement of GDP is often criticised. It leaves out, for example, the value of housework and any costs associated with the depletion of resources. Many economists find these criticisms intensely irritating, because we are perfectly aware of what we are trying to measure with GDP. Simon Kuznets, who received the Nobel Prize for his work, pioneered the measurement of GDP in the 1930s, and it is clear from his writings at the time what he was and was not trying to measure. The world economy had just experienced what was obviously a catastrophic drop in real output. We now estimate, for example, that between 1929 and 1933, real GDP in America fell by over 20 per cent (compared to just 3 per cent in the late 2000s). The overwhelming demand from policy makers was for a systematic way of measuring output in the market economy. This was the task Kuznets faced, and it was the task which he carried out.

The challenge is not the measurement of the costs of resource depletion, to give an example. Economists have been at the forefront of such efforts for several decades (for example [28]). Rather, it is the more fundamental issues raised by the measurement of output in the cyber economy.

The lack of information on productive knowledge, for example, is a major deficiency of the current system of national accounts. The work of R. Hausman [29] and L. Pietronero [30] has made important advances here, focused as it is on the capabilities which are at the heart of trading relationships. Innovation can no longer be treated as the residual output after more easily measurable inputs and outputs are counted. Innovation has been a core element in new firm creation and this was true even when national accounts were being invented.

The difficulties of valuing innovative products and services, especially in terms of their contribution to real output, are well known [for example 31].

A challenge is the valuation of what are essentially public goods created in cyber society. How is value to be assigned in the rapidly growing, so-called *prosumer* sector (i.e. production and development by consumers) of the economy? The activity of much of this sector corresponds closely to the classic definition of public goods, in that the output is both non-excludable and non-rivalrous.

The issue can perhaps be illustrated with a concrete example. In recent years, the statistical package R has become the package of choice for young scientists in a wide range of disciplines around the world (https://www.r-project.org/). A huge range of routines can be downloaded. It is, in the everyday sense of the word, a very valuable tool for conducting almost any conceivable kind of statistical analysis. Its graphics features are illuminating. But R, and all the routines associated with it, can be downloaded for free. True, R has now become so widely used that a Foundation has been set up to support developments. The foundation, however, is a "not for profit organization working in the public interest". It does attract a certain amount of funding, and so its output could be measured using conventional national accounting techniques. The value of R, intuitively, seems to be rather considerably greater than this.

6 Concluding remarks

In terms of concluding remarks, it should be a source of real concern to econophysicists that, despite the advances which they have made in scientific knowledge, the intertwined worlds of both economists and policy making continue to operate almost orthogonally from the econophysics community.

Econophysicists need to be more aware of the incentives and motivations of policy makers. Doing good science is a necessary but not sufficient condition to get their attention. Equally, they need to be more willing to engage with economists, rather than simply attempting to import the methods of statistical physics into economics without sufficient awareness of what has already been done within economics and of the ability of economists to modify this approach in ways which make it more acceptable. Economics is not an empty box.

There are three major areas in which econophysicists, in collaboration with economists, have a great opportunity to make an impact. All three involved network science and the interrogation of Big Data, not from a purely data driven perspective, but filtered through the lens of an appropriate theory:

– Developing a model of agent behaviour which explains agent behaviour in cyber society better than the economic model of rational choice;
– Obtaining a better understanding of the fluctuations in output over the business cycle than mainstream economics;
– Developing measures of output in cyber society.

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