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Econophysics: origin, basic principles and perspectives

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Glossary

Cross national comparisons: Comparing cross-national data for a specific phenomenon, e.g. a surge in housing prices, is the key to distinguishing between essential factors which are common to all episodes and those which are accessory and context dependent.
Economathematicians: Mathematicians or theoretical physicists who develop mathematical tools, models or simulations for social phenomena but do not try to confront these models to actual observations.
Econophysics: A field of physics which originated in the mid-1990s. Throughout this article, we use the term in a broad sense which includes econophysics, sociophysics and historiophysics. As a matter of fact, these fields can hardly be studied separately in the sense that economic effects depend upon social reactions (e.g. reactions of consumers to advertising campaigns); furthermore, economic investigations crucially rely on statistics which typically must combine present-day data with data from former historical episodes.
Econophysicists: Physicists who study social, economic or political issues.
Endogenous mechanisms: Models usually describe endogenous mechanisms. For instance a population model would describe how people get married and have children.
Exogenous factors: Exogenous factors are more or less unexpected external forces which act on the system. Thus, for a population wars or epidemics may bring about sudden population changes. It is only when exogenous factors are recurrent and fairly repetitive that they can be taken into account in models.
Experiment: Apart from its standard meaning in physics or biology we also use this term to designate the process of (i) defining the phenomenon that one wants to study (ii) locating and collecting the data which are best suited for the investigation (iii) analyzing the data and deriving *regularity rules* or testing a model.
Model testing: Before confronting the predictions of a model to statistical evidence it is necessary

to ensure that the system was not subject to unexpected exogenous shocks. The impact of exogenous factors which are not accounted for in the model must in some way be removed, that is to say the data must be corrected in a way which takes these shocks out of the picture. Usually, such corrections are very tricky to implement.

1 Definition of the subject and its importance

> "No science thrives in the atmosphere of direct practical aim. We should still be without most of the conveniences of modern life if physicists had been as eager for immediate applications as most economists are and always have been."
>
> J. Schumpeter [10] (1933, p. 6)

> "The free fall is a very trivial physical phenomenon, but it was the study of this exceedingly simple fact and its comparison with the astronomical material which brought forth mechanics. The sound procedure [in every science] is to obtain first utmost precision and mastery in a limited field, and then to proceed to another, somewhat wider one and so on."
>
> J. Von Neumann and O. Morgenstern [5] (1953)

These two quotes define fairly well the path that econophysics tries to follow. They both insist on the fact that one should begin by focusing on simple phenomena even if at first sight they have little practical implications. In what follows we will develop this point but first of all we must address a question which comes to the mind of all persons who hear about econophysics for the first time, namely:

> "Why should physicists have something to say about economic and social phenomena. Admittedly, biology can benefit from physics because of the means of observation [e.g. exploration of protein molecules by X-ray scattering] that it provides, but there are no similar needs in economics."

I have heard this question asked repeatedly by many of my colleagues. In my answer I usually emphasize that what matters is more the method of investigation than the phenomena by themselves. I stress that applying to the social sciences the experimental methodology invented by physicists and chemists would mark a great progress. However, with the benefit of insight, I realize that these answers may have appeared far fetched and unconvincing to many of my listeners. A better and more factual claim is to observe that over the past century several of the most renowned economists and sociologists were in fact econophysicists in the sense defined in the glossary. Indeed, back in the nineteenth century, the only way to get a decent mathematical training was to study astronomy, engineering, mathematics or physics. When such people entered the social sciences this lead to two kinds of approaches which we may designate as econophysics and economathematics (see the glossary). In the first category one may mention the astronomer Adolphe Quételet (1796-1874), Clément Juglar (1819-1905) educated as a medical doctor, Vilfredo Pareto (1848-1923) educated as an engineer, the mathematician Louis Bachelier (1870-1946), the physicist Elliott Montroll (1916-1983), the mathematician Benoît Mandelbrot (1924-). In the second category one may mention Léon Walras (1834-1910) who was educated as an engineer, the astronomer Simon Newcomb (1835-1905), the physicist Maurice Allais (1911-).

Of course, if the economic discipline had been highly successful there would be little need for an alternative approach. However, great doubts have been expressed by some of the most renowned economists about the attainments of their discipline. We have already cited Schumpeter's opinion on this matter. In addition one may mention the judgments of Vassily Leontief, Anna Schwartz,

Lawrence Summers or the thesis developed in a recent book by Masanao Aoki and Hiroshi Yoshikawa.

- Leontief and Schwartz emphasized that the present organization of economic research discourages observational research. In Schwartz's words ([11]) [1]

> The main disincentive to improve the handling and use of data is that the profession withholds recognition to those who devote their energies to measurement. Someone who introduces an innovation in econometrics, by contrast, will win plaudits.

- The assessment made by Summers in a paper published in 1991 is well summarized by its title: "The scientific illusion of empirical macroeconomics".
- In their book, Aoki and Yoshikawa ([1], p. 25) point out that the representative agent assumption which is supposed to provide a connection between micro- and macroeconomics is fundamentally flawed because it neglects both social variability and stochastic fluctuations. It may be true that in recent years a greater emphasis has been put on the issue of heterogeneity. Yet, is this the right way to takle the problem? A model is a simplification of reality anyway, so if it is no tenable to use loosely defined representative agents, an alternative solution may be to focus on sharply defined agent's attitudes. For instance, whereas without further specification home buyers may not be well defined as a useful category, the behavior of investors during the final phases of speculative price peaks may be sufficiently recurrent to make up for a well defined category.

2 Introduction

What are the main characteristics of econophysics? In what follows we will try to summarize some basic principles. Each of them will be illustrated by one or several studies performed by econophysicists over the past decade. Although the wording that we use is fairly personal, we believe that fundamentally these principles are shared by many econophysicists. In the course of more than a decade, econophysics has become a big tree with many branches. Obviously it is impossible to describe all of them if only because the knowledge and understanding of the present author is limited. He apologizes in advance for his limitations and for the fact that the present selection is by necessity fairly subjective.

3 The primacy of observation

Econophysics started around 1995 in sync with the creation of huge computerized databases giving minute by minute transactions on financial markets such as the New York stock market, the dollar-yen exchange rate, the forward interest rates or providing individual income data for millions of people. It may be estimated that between 1995 and 2005 about two thirds of the papers published by econophysicists aimed at deriving *regularity rules* from such databases. Let us illustrate this point by the case of income data. Since Pareto's work we know that the distribution of high incomes can be described by a power law with an exponent α comprised between 1 and 1.5. With databases comprising millions of income data one can get high accuracy estimates for α and observe how α changes as the result of economic booms or stock market crashes. It turns out that α decreases during booms and increases in the wake of stock market collapses ([6]).

[1] Leontief ([3], p. xi) has even stronger words: "The methods used to maintain intellectual discipline in this country's most influential economics departments can occasionally remind one of those employed by the Marines to maintain discipline on Parris Island [a training camp of U.S. Marines].

Other empirical investigations were carried out in the past decades. We list some of them below. The list is arranged by topic and by research teams.

- Stock transactions, (i) Boston University: see publications involving G. Stanley. (ii) CEA (i.e. Commissariat à l'Energie Atomique which means Institute for Atomic Research) and "Science-Finance": see publications involving J.P. Bouchaud. (iii) Nice University and UCLA: see publications involving D. Sornette. (iv) University of Warsaw: see publications involving J. Kertesz.
- Forward interest rates, Singapore University: see publications involving B. Baaquie.
- Exchange rates, Zurich: see publications involving M. Dacorogna.

To many physicists the statement that observation is supreme could seem self evident. In economics, however, such a statement represents a revolution. We already mentioned the fact that observation is a neglected topic in economics. As a matter of fact, before econophysics started it was impossible to publish a paper which would identify *regularity rules* without at the same time providing a model[2].

4 Investigating one effect at a time

In most natural phenomena different effects occur simultaneously. For instance, if one leaves a glass of cold water in the sun, the water will of course get warmer but if one looks at the mechanisms which are implied this involves many different effects: interaction of light and water, interaction of light and glass, conduction of heat, creation of convection currents between layers of water which are at different temperatures, and so on. One of the main challenges of physics was to identify these effects and to study them separately. Similarly, most social phenomena involve different effects; thus, one of the main tasks of the social sciences should be to disentangle and decompose complex phenomena into simple effects. In principle this is easier to do in physics than in the social sciences because one can change experimental conditions fairly easily. However, history shows that the main obstacle are conceptual. The previous phenomenon involves the transformation of one form of energy (light) into other forms of energy and it is well know that it took centuries for a clear understanding of these processes to emerge. In order to convince the reader that the same approach can be used in the social sciences we briefly describe a specific case.

Suicide is commonly considered as a phenomenon which is due to many factors. One of them is the strength of the marital bond. How can we isolate that factor? Of course, it is impossible to isolate it completely but one can at least make it so predominant that other factors become negligible. To achieve that objective, we consider a population in which the number of males is much larger than the number of females. Such a population will necessarily have a large proportion of bachelors and therefore will be an ideal testing ground to study the role of the marital bond. Where can we find populations with a large excess of men? Almost all populations of immigrants are characterized by an excess of males. It turns out that due to specific circumstances, this imbalance was particularly large in the population of Chinese people living in the United States. By the end of the 19th century there were about 60 Chinese men for one Chinese woman[3].

What makes the present principle important? Unless one is able to estimate the impact of each factor separately, one will never gain a *lasting* understanding. It is important to understand why. In the econometric approach one would conduct multivariate regressions of the temperature as a function of various (pre-conceived) parameters such as the volume of the liquid, the thickness of the glass and

[2] In what economists call "empirical econometrics" the researcher necessarily must provide a multivariate econometric model which means that even before he analyses the data he already knows the theory which rules the phenomenon. Moreover, all factors whether they have a weak or a strong impact are treated on the same footing. As we will see in the next point this has important implications.

[3] For more details about this case, see [9].

so on. Now suppose we wish to predict what happens when water is replaced by black ink. As a result of greater light absorption temperature differentials will be larger and convection currents will be stronger. The fact that many effects change at the same time will make the multivariate estimates irrelevant. Unless one has an understanding of the various individual effects it will be impossible to make any sound prediction. To sum up, any major change in business and social conditions will invalidate the previously accepted econometric models. This explains why the econometric approach fails to ensure that knowledge grows in a cumulative way.

5 What guidance can physics provide?

One can recall that the experimental methodology pioneered by researchers such as Tycho Brahe (1546-1601), Johannes Kepler (1571-1630) or Galileo (1564-1642) marked the beginning of modern physics. Two centuries later, that methodology was adapted to the exploration of the living world by people such as Claude Bernard (1813-1878), Louis Pasteur (1822-1895) and Gregor Mendel (1822-1884). In a sense it is a paradox that this method has been used successfully for the understanding of living organisms but has not yet gained broad acceptance in the social sciences for it can be argued with good reason that living organisms are more complex systems than are states or societies[4]. In short, applying the experimental methodology to the social sciences is a move which seems both natural and long overdue. Actually, serious efforts were made in this direction by social scientists such as Emile Durkheim (1858-1917) or Vilfredo Pareto (1848-1923) but this route seems to have been sidetracked in the second half of the 20th century.

Can we use the mathematical framework of physics in the investigation of social phenomena? This approach has been tried with some success by renowned econophysicists such as Belal Baaquie and coworkers (2004, 2007) and Jean-Philippe Bouchaud and coworkers ([2],[4]). In those cases the success must probably be attributed to the fact that the methods of theoretical physics which were used could be formulated in a purely mathematical way which did not rely on any physical concepts such as energy, momentum or temperature. As we do not yet know how these notions should be transposed to social systems, it seems impossible to apply the formalism of statistical mechanics to social phenomena[5] .

Our claim that the experimental methodology of physics can be used to explore social phenomena must be substantiated by explaining how it is possible to carry out “experiments” in social phenomena. This is the purpose of the next section.

6 How cross-national observations can be used to test the role of different factors

Nowadays when a solid state physicist wants to measure, say, the interaction between ultraviolet light and a crystal of germanium, the experiment involves little uncertainties. That is so because this field

[4]We will not develop this point here but it can be observed that a bacteria or a cell contains thousands of different proteins which interact in various ways. In the same line of thought one may recall that living organisms have been around for several billions years whereas societies appeared less than 100,000 years ago and states less than 10,000 years ago.

[5]It could be argued that one is free to define “social energy” in the way which one wishes. However, one should remember that the notion of energy is pivotal in physics only because it is ruled by (experimentally proved) conservation laws, such as the equivalence between heat and mechanical energy demonstrated by James Joule. Naturally, prior to defining a “social temperature”, it would seem natural to define a herd- or swarm-temperature describing aggregated populations of bacteria, insects or animals. As far as we know, no operational definition of this kind has yet been proposed.

of physics is already well understood. On the contrary, in the case of new and not well understood phenomena there is considerable uncertainty about the specific conditions of the experimental set up. In the two years after Léon Foucault demonstrated the Foucault pendulum experiment, at least twenty physicists tried to repeat it. Some succeeded while others did not. Indeed the experimental conditions, e.g. the length of the pendulum or the nature of the suspension wire, ensuring that the Foucault effect will be observed were not well understood. It is only through various attempts with different settings that a better understanding progressively emerged. For instance it was realized that by using a pendulum of great length one would be able to reduce two undesirable effects (i) the sensitivity of the pendulum to exogenous noise [6] (ii) the Puiseux effect which generates a rotation of the oscillation plane which interferes with the Foucault effect.

Few (if any) sociological phenomena are well understood which means that social researchers are basically in the same situation as those physicists in the years 1851-1852 who tried to observe the Foucault effect[7]. As an illustration suppose we wish to know if the publication of a specific type of news has an effect on the number of suicides[8]. Such an observation depends upon many parameters: the nature of the news and the amount of attention that it receives, the time interval (days, weeks or months?) between the publication of the news and the occurrence of the suicides. In addition one does not know if there will be an increase or a decrease in the number of suicides, if men will be more or less affected than women, and so on. All these questions can in principle be answered by conducting many observations in different countries and in different periods of time. In other words, if we are sufficiently determined, patient and tenacious and if we can get access to the statistical data that are needed, we should be able to disentangle and unravel the phenomenon under consideration in the same way as experimenters have been able to determine how the Foucault effect can be observed.

7 How vested interests may affect the accessibility and reliability of social data

So far we have emphasized the similarities between natural and social phenomena but there are also some stumbling blocks which are specific to the social sciences. One of them is the fact that some data may have been altered or swept under the carpet by some sort of ideological, political or social bias, pressure or interference. Needless to say, extreme care must be exercised in such cases before making use of the data.

As an illustration, suppose that an econophysicist or a sociologist wants to study episodes of military occupation of one country by another. Such episodes are of particular interest from a sociological perspective because they bring about strong interactions and can serve to probe the characteristics of a society. Moreover, because armies display many similarities no matter their country of origin, such episodes offer a set of *controlled experiments*. Naturally, in order to be meaningful the comparison must rely on trustworthy accounts for each of the episodes. Unfortunately, it turns out that in many cases only scant and fairly unreliable information is available . Consider for instance the occupation of Iceland by British and American forces during World War II. Among all occupation episodes this one was particularly massive with troops representing 50% of the population of Iceland prior to the

[6] Indeed, it is when the speed of the pendulum goes through zero that it particularly sensitive to external perturbations; increasing the length of the pendulum reduces the number of oscillations in a given time interval and therefore the drift due to noise.

[7] As a more recent and even less understood case, one can mention the physicists who keep on trying to observe the cold fusion effect.

[8] This question is connected to what is known in sociology as the Werther effect; for more details see the papers written by Phillips (in particular [7]) and [9, chapter 3].

occupation. The same proportion in a country such as Japan would have meant 30 million occupation troops that is 60 times more than the peak number of 500,000 reached at the end of 1945. Quite understandably for such a high density of troops, there were many incidents with the population of Iceland[9]; yet, is is difficult to find detailed evidence. Due to the paucity of data a superficial investigation would easily lead to the conclusion that there were in fact only few incidents. It does not require much imagination to understand why this information has not been released. The fact that in a general way all countries whatsoever are reluctant to recognize possible misconduct of their military personnel explains why the information is still classified in British and American archives. Because Iceland and the United States became close allies after 1945, one can also understand that the Icelandic National Archive is reluctant to release information about these incidents. The same observation also applies (and for the same reasons) to the occupation of Japan, 1946-1951; for more details see Roehner (2007, p. 90-98). Naturally, similar cases abound. Due to a variety of reasons well-meaning governments, archivists and statistical offices keep sensitive files closed to social scientists. Most often it is in fact sufficient to catalog sensitive file units in a fairly obscure way. The plain effect is that the information will not be found except perhaps by pure luck, a fairly unlikely prospect in big archives.

8 How can exogenous factors be taken into account?

This question is not specific to social phenomena, it is also of importance in physics. As a matter of fact, in astronomy it provides a powerful method for observing objects that cannot be observed directly. Thus, we know the existence of exoplanets only from the perturbing effect which they have on the position of the star around which they move. However, for social phenomena the problem of exogenous factors is much more serious because (i) they may not be known to observers (ii) even once they are identified it is very difficult to correct the data in a reliable way. One of the main pitfalls in the modeling of socio-economic phenomena is to explain them through endogenous mechanisms while they are in fact due to exogenous factors. The following examples make clear that this difficulty exists for many phenomena, whether they belong to the financial, economic or social sphere.

- In their paper of 2005 about consensus formation and shifts in opinion Michard and Bouchaud confront their theory to two classes of social phenomena: (i) the diffusion of cell phones (ii) the diffusion of birth rate patterns. In the first case it is clear that advertising campaigns may have played an important role. Of course, one could argue that these campaigns were part of the endogenous diffusion process. However, this argument does not hold for big telecom companies (e.g. Vodafone) which operate in many countries. In such cases the decision about the magnitude of the advertising campaigns are taken by the board of the company which means that such campaigns can hardly be considered as endogenous effects. Similarly, birth rates depend upon exogenous factors. For instance the length of time spent in higher education has an effect on the average age of marriage and the later has an effect on birth rates.
- On 21 July 2004 the share price of Converium, a Swiss reinsurance company listed on the New York Stock Exchange dropped 50%. Was this fall the result of an avalanche effect due to a movement of panic among investors? In fact, the most likely explanation is that it was the consequence of a decision taken by the board of Fidelity International, a major investment fund and one of the main shareholders of Converium. Indeed in a statement issued by Converium on August 3, 2004 it was announced that Fidelity had reduced its holdings from 9.87% to 3.81%. In other words, it would

[9] According to a report that Prime Minister Hermann Jonasson sent to the American Headquarters, there were 136 incidents between troops and Icelanders during the period between July 1941 (arrival of the American troops) and April 1942 (Hunt 1966) in Reykjavik alone. Unfortunately, no copy of this report seems to be available at the National Archives of Iceland.

be completely irrelevant to explain such a fall through a herd effect model or through any other endogenous mechanism (more details can be found in [8]). Similar conclusions apply to corporate stock buybacks, as well as to mergers, acquisitions, buyouts and takeovers; in all these cases decisions taken by a few persons (the average board of directors has nine members) may trigger substantial changes in share prices. How should such effects be taken into account by stock market models?

- At the end of 2004 and in the first months of 2005 British housing prices began to decline after having risen rapidly during several years. Yet after May 2005, they suddenly began to pick up again at an annual rate of about 10%. This resurgence was particularly intriguing because at the same time U.S. housing prices began to decline. To what factor should this unexpected rise be attributed? Most certainly this was the market response to a plan introduced by the Chancellor of the Exchequer Gordon Brown in late May (The Economist May 28, 2005). Under this plan which aimed at propping up house prices new buyers would benefit from a zero-interest loan for 12% of the price. In addition, the government would cover all losses incurred by banks as a result of possible bankruptcies of borrowers (at least so long as prices did not fall by more than 12%). It appears that the plan indeed propped up the market. Consequently, in order to confront the predictions of any model (e.g. see Richmond's paper which was published in 2007) with observation the impact of this plan effect must first be taken out of the picture.

- The same difficulty is also encountered in socio-political phenomena. Here is an illustration. On 5 October 2000, in protest against the publication of the results of the presidential election there was a huge mass demonstration in Belgrade which involved thousands of people from the provinces who were transported to the federal capital by hundreds of buses. It clearly showed that president Milosevic was no longer in control of the police and army and lead to his retirement from the political scene. Thus, what NATO air strikes (24 March-11 June 1999 [10]) had not been able to achieve was accomplished by one night of street demonstrations. What was the part of exogenous factors in this event? Although in many similar cases it is very difficult to know what really happened, in this specific case a partial understanding is provided by a long article published in the New York Times[11]. In this article we learn that several American organizations belonging to the intelligence network supported, financed and trained Serbian opposition groups. For instance the article mentions the Albert Einstein Foundation, the International Republican Institute, the National Endowment for Democracy, the U.S. Agency for International Development. Although the amount of the total financial support is not known, the New York Times article says that it exceeded $ 28 million. The plan comprised two facets: the organization of demonstrations on the one hand and the infiltration of the army and police on the other hand in order to undermine their loyalty and convince them to remain passive during the demonstrations. According to the article this second facet remains classified. With an exogenous interference of such a magnitude, it would clearly be meaningless to describe this upheaval as a purely endogenous process. Moreover, the fact that we have only partial knowledge about the exogenous forces makes it very difficult (if not altogether impossible) to come up with a satisfactory description. It should also be noted that the influence of these groups did not disappear overnight after October 4, which means that the subsequent history of Serbia must also take them into account at least to some extent.

[10] It can be noted that similarly to what would happen in 2003 for the invasion of Iraq, these air strikes were carried out without the authorization of the United Nations Security Council.

[11] New York Times, Sunday 26 November 2000, Magazine Section, p. 43, 7705 words; the article by Roger Cohen is entitled: "Who really brought down Milosevic". What makes this account particularly convincing is the fact that it was preceded by another article entitled: "U.S. anti-Milosevic plan faces major test at polls" which appeared on September 23, 2000 (p. 6, 1150 words). Two weeks *before* the events, this article described the way Milosevic would be removed from power. The article makes clear that the plan would be carried out no matter what the results of the election would be.

9 Future directions

In this article we have described the challenges and obstacles to which one is confronted in trying to understand socio-economic phenomena. In parallel we have shown that the econophysics approach has many assets. One of them which has not yet been mentioned is the fact that econophysicists are not subject to the rigid barriers which exist between various fields and subfields of the human sciences. Thus, if it turns out that in order to explain an economic phenomena one needs to understand a social effect, econophysicists would have no problem in shifting from one field to another. There is another historical chance that we have not mentioned so far, namely the development of the Internet. In the past decade 1997-2007 the amount of information to which one has access has increased tremendously. Electronic catalogs of major libraries or of national archives, indexes of newspaper, search engines on the Internet, searchable databases of books, all these innovations contributed to give the researcher easy access to information sources that have never been available before. In particular it has become fairly easy to find cross-national data. Thus, social scientists and econophysicists are in a better position than ever for carrying out the kind of comparative studies that we called for in this article.

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Further reading

Two observations are in order about this reference section.

- Many of these references are not mentioned in the text; the objective is to give readers a starting point for further readings on various aspects of econophysics.
- There is a fairly complete list of publications of the present author; it is given for the purpose of illustrating through one specific case the "trajectory" of an econophysicist in the course of time (1995-2007).

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