Preface

Econophysics describes phenomena in the development and dynamics of economic systems by using of a physically motivated methodology. First of all, Mandelbrot had analyzed economic and social relations in terms of modern statistical physics. Since then, the number of publications related to this topic has increased irresistible greatly. To be fair to this historical evolution, I point out, however, that physical and economic concepts had already been connected long ago. Terms such as work, power, and efficiency factor have similar physical and economic meanings. Many physical discoveries – for instance in thermodynamics, optics, solid state physics, or chemical physics – correspond to a parallel evolution in the fields of technology and economics.

The term econophysics, or social physics, also is not a recent idea. For example, in the small book *Sozialphysik* published in 1925 [221], R. Lämmel demonstrates how social and economic problems can be understood by applying simple physical relations. Of course, the content of early social physics and the topics of modern econophysics are widely different. Nevertheless, the basic idea (i.e., the description and the explanation of economic phenomena in terms of a physical theory) did not change over the whole time. At this point, an important warning should be pronounced. Econophysics is no substitute for economics. An economic theory differs essentially from what we understand as econophysics. Of course, a short definition of economics is not very simple, even for seasoned economists. A possible working definition may be: Economics is the study of how people choose to use scarce or limited productive resources to produce various commodities and distribute them to various members of society for their consumption. This definition suggests the large variety of disciplines combined under the general term economics: microeconomics, controlling, macroeconomics, finance, environmental economics, and many other scientific branches are usually considered a part of economics.

From this short characterization of economics, it is obvious that the aims of economic investigations and physical research are strongly different. Therefore, the question remains how physical knowledge may contribute to progress in the understanding of the dynamics of economic systems. As mentioned above, it is not the aim of econophysics to replace some or all of the traditional and modern economic sciences by new, physically motivated theories and methods. The key to answering the question is given by two essential terms: the methodology of physics and the statistical physics of complex systems.

The successful evolution of physics during the last three centuries rests on its methodology, which can certainly be described as being analytical. This means that by decomposing a system into its parts, a physicist may try to understand the properties of the whole system.

In particular, the physical experiment plays a central role during the formation of new physical knowledge. Especially, the reproduction of the results in the course of a well-defined experiment backs up physical theories. A well-established theory then allows predictions about very complicated systems that were never analyzed before by physical methods or that cannot be investigated by physical experiments. A traditional example is astronomy. The motion of planets may be observed with sufficiently complicated instruments, but these observations are not reproducible experiments in a physical sense. On the other hand, gravitational law can be checked by various lab experiments. With knowledge of gravitation theory and starting from well-defined initial conditions, we are able to calculate the motion of planets over a sufficiently long period in agreement with astronomical observations.

A similar situation occurs also for complex systems. General evolution laws, limit probability distribution functions, and universal properties may be checked experimentally for simple systems and allow us to formulate a general theory. If we have obtained such a suitable theory about the behavior of several complex systems, we may use this knowledge also for the analysis of more complicated systems.

We should be aware that the degree of complexity of the economic world is extremely high, which means that usually it is not possible to make economic observations under the controlled experimental conditions characteristic of scientific laboratories. As a result of this limitation, the quantitative economic knowledge is far from complete. However, econophysics may give a consequent basis for the interpretation of the structure and dynamics of economic systems or subsystems such as financial markets or national economies.

The main goal of the book is to present some of the most useful theoretical concepts and techniques for understanding the physical ideas behind the evolution and the dynamics of economic systems. But it should be remarked that the concepts and tools presented are also relevant to a much larger class of problems in the natural sciences as well as in the social and medical sciences. The only condition is that the underlying systems be classified as sufficiently complex. From this point of view, the mathematical background and the general theoretical concept used for the analysis of economic systems may be helpful also for the description of social systems, biological organisms, populations, communication networks, biological evolution processes, meteorology, turbulence, granular matter, epidemics, the geosciences, and so on.

The central theme of the book is that of collective and cooperative properties in the behavior of economic units, such as firms, markets, and consumers. It is very important to understand these properties as a consequence of the interaction of a large number of degrees of freedom. This fact allows us to describe economic phenomena using modern physical concepts, such as deterministic chaos, self-organization, scaling laws, renormalization group techniques, and complexity, but also traditional ideas of fluctuation theories, response theory, disorder, and non-reproducibility.

Obviously, an applicable description of a complex system requires the definition of a set of relevant degrees of freedom. The price one has to pay is that one gets practically no information about the remaining irrelevant degrees of freedom. As a consequence, the theoretical basis used for the analysis of economic processes can be described as a probabilistic theory. The more or less empirical specification of the relevant and irrelevant degrees of freedom is influenced by the scales in mind. Characteristic physical scales are time and length scales. In economics, an additional scale, the so-called price scale, has often been taken into account. Econophysics focuses its attention on the description of economic problems in terms of various scales. These scales of interest determine the choice of the relevant degrees of freedom and the mathematical method for solving the underlying problem.

The first two chapters cover important notations of complex systems and the statistical physics of out-of-equilibrium systems considering the dominant scales and the relevant degrees of freedom, respectively. The mathematics is presented in a simple and intuitive way whenever possible with respect to the mathematical rigor.

The third chapter deals with problems related to financial markets. Although finance and financial mathematics offer a large number of different concepts and mathematical instruments to solve various practical problems, the physical concept presented provides a way to derive the complicated, partially anomalous fluctuations of stock prices and exchange rates from general, universal laws. Additionally, this chapter extends the mathematical and physical tools, for instance by introducing the concept of the renormalization group approach, the generalized central limit theorem, and the theory of large fluctuations.

The fourth chapter considers economic problems that are not directly connected with the dynamics of markets. Microeconomics, the limitation of thermodynamic concepts in the economy, environmental economics, and macroeconomics are discussed in terms of deterministic chaos, stability theory, scaling laws, field theories, and self-organized criticality.

In the subsequent chapter, several numerical methods used for the solution of economic problems are discussed and compared with similar physical techniques. Especially, various kinds of Monte Carlo simulations (dynamical, reversed, and quasi-Monte Carlo) and cellular automaton theories will be introduced.

The last chapter gives an overview of several methods that may be applied for the prediction of the evolution of economic phenomena and for the estimation of general trends in the evolution of economic systems.

This book derives from a course taught several times at the university at Ulm in the Department of Theoretical Physics starting in 2000. Essentially aimed at students in econophysics, the course attracted students, graduate students, and postdoctoral researchers from physics, chemistry, economics, and financial mathematics. I am indebted to all of them for their interest and their discussions.

The course itself contains also some lectures about the dynamics of traffic and communication networks. These are not included in this book but instead I refer the reader to the comprehensive specialiced literature.

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