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# Driving Forces in Physical, Biological and Socio-Economic Phenonema

## A Network Science Investigation of Social Bonds and Interactions

Facts are stubborn things; and whatever may be our wishes, our inclinations, or the dictates of our passions, they cannot alter the state of facts and evidence.

John Adams, December 1770

We continued our systematic survey of the edge of the sodden portion of the moor, and soon our perseverance was gloriously rewarded. Right across the lower part of the bog lay a miry path. Holmes gave a cry of delight as he approached it. “Here is Herr Heidegger, sure enough! My reasoning seems to have been pretty sound, Watson.”

Sir Arthur Conan Doyle, The Priory School (1905)

# Preface

The purpose of this book is to explore the similarities as well as the differences between natural and social phenomena. While several chapters are devoted to the second objective, the main message of the book is to show that the experimental methodology which has been used so successfully in the natural sciences can also be applied to social phenomena.

Basically, one can distinguish two main approaches in the social sciences, the anthropomorphic perspective and the system theory approach. Throughout this book we try the second of these options. In order to illustrate them, let us consider the phenomenon of suicide. In the anthropomorphic perspective one will try to establish connections between suicide and psychiatric disorders. In the system theory approach one tries to formulate the problem of suicide in a more general framework in which the interactions between the elements composing the system play the key role[1]. This approach was pioneered by the sociologist Emile Durkheim at the end of the nineteenth century. He was able to show that there is a clear relationship between the likelihood of suicide and the strength of the bonds which link an individual to the rest of the society. The main challenge (and prerequisite) in the application of the network science approach is to be able to estimate the strength of the interactions between the elements of the system. This is also the main stumbling-block because both system theory and network science are mathematical frameworks which provide useful modeling tools but do not tell us how to investigate complex, interconnected networks and how to measure the interactions between their elements. Network theory will not show us how complex problems can be simplified, nor will it tell us anything about experimental procedures aimed at estimating the strength of bonds. In short, although we need some guidance for the exploration of this new and uncharted territory we hardly find it in network science alone.

Is there another field which can guide us? Physics and chemistry have been trying to understand systems of interacting entities for over three centuries. In situations where one is confronted to an opaque maze of interconnected and multifaceted systems, chemistry and physics have developed methods which enable us to probe one kind of interaction at a time, for instance by exploring the phenomenon at different scales in space and time. This is why in this book we often use such methods as a source of inspiration, a reservoir of ideas and solutions. Parallels between physical and social phenomena could be seen merely as analogies; that would be a narrow perspective, however. In our view these parallels reflect real underlying similarities in terms of interactions and network structures. Naturally, we understand and accept the fact that this is a point on which opinions may differ. The ultimate test is whether this approach can help us to build up a better understanding of social phenomena.

To carry out this program one needs to take a fresh look not only at social phenomena but also at physics. Indeed, if parallels with social phenomena are to be found it is certainly not at the level of fields such as general relativity or string theory that they can be discovered. The parts of physics which seem the most promising are for instance the rules which describe the mixture and miscibility of

[1]As a consequence this approach is not restricted to human societies but may be extended (at least if the interactions are similar) to biological or physical systems. Such a perspective was developed by system theory in the 1960s and 1970s and was revisited and revived by network science in the late 1990s and early 2000s.

liquids, the solubility of gases in liquids, phase transitions between different allotropic structures and other similar issues. Such questions were actively investigated in the nineteenth and early twentieth centuries but are somewhat neglected nowadays. This is why our exploration is also a journey in some forgotten corners of physics. In a general way, our sources of inspiration are not so much the mathematical theories of the physical phenomena under consideration, but rather their understanding in terms of molecular mechanisms and interactions.

During past decades social scientists have had increasing recourse to mathematical tools whether in the form of statistical tests, computer simulations or mathematical models. This may give the impression that these models have become more "scientific" and in a sense closer to the natural sciences. However, this observation is called into question by two observations.

- First, and somewhat surprisingly, a similar evolution is underway in physics as well. As an illustration, one can mention the fact that between 1900 and 2000 the proportion of purely theoretical papers in *Physical Review*, one of the main physical journal, has increased from 10% to 55% [2]. Does this increased mathematization mean that physics has become more scientific and more productive than it was in the early twentieth century, a time marked by the emergence of statistical physics, quantum mechanics and general relativity? For a solution of this paradox, one should recall that "more mathematical" does not necessarily mean "more scientific" and vice versa. As an illustration, let us consider Galileo's celebrated experiment of a ball rolling down a ramp which is viewed as the starting point of modern physics. This experiment can be set up and interpreted without any mathematical knowledge beyond basic arithmetic. The law governing falling bodies derived from the experiment was stated by Galileo in the following terms: "We always found that the spaces traversed by the ball were to each other as the squares of the times and this was true for all inclinations and for all balls[3]. What was really new in this experiment was that (i) it concerned a *simple* phenomenon in the sense that its design made friction and other side effects almost negligible (ii) the measurements were carried out with high accuracy and repeated a great number of times, "a full hundred times" writes Galileo. We will see in a subsequent chapter why the number of repetitions is a crucial element in the battle against noise.

These observations suggest three key conditions of a scientific observation: (i) To investigate one phenomenon at a time (ii) To make sure that the system under consideration is closed, or if it is not, that all exogenous factors are duly taken into account. (iii) To carry out the measurements with utmost accuracy. These rules are of course well known, but paying lip service to them is not sufficient; in truth, in the social sciences they are rarely applied. The first rule is probably the most difficult to comply with because most questions in the social sciences are multifaceted issues which have no real meaning unless one is able to disentangle the various mechanisms which are involved. The second rule has also broad implications. Historians, especially when they write the history of their own country, have a marked tendency to forget, discard or belittle exogenous influences. In writing an history of the administration of justice in France it probably makes sense to neglect exogenous factors, but writing a history of French labor unions in the twentieth century without due recognition of American or Soviet interferences would make little sense. Similarly, a history of the French Revolution leaving out British influence and interventions would not be very realistic. And yet, most of the works on these topics devote at best a few lines to such exogenous factors. The question of hidden exogenous

[2] By "purely theoretical" we mean papers that do not make contact with actual data. At the same time the proportion of experimental papers has decreased from 85% to about 35%; a third but rather small category of papers is represented by theoretical papers which make contact with experimental results. If this evolution continues, by 2050 experimental and purely theoretical papers will represent 15% and 80% respectively. (for more details see, Roehner (2004, p. 327)).

[3] Dialogue concerning two new sciences, Macmillan, 1914 (p. 178).

influence will be considered in more detail in a subsequent chapter.

One explanation of the gap between physics and the social sciences can be found in their different traditions regarding the question of how to make measurements[4]. Physicists believe in laws which have a permanent and universal validity. They are prepared to devote years or even decades to establishing, validating and confirming such laws. As an example, one can mention the experimental tests of the theory of general relativity. They began in 1919 when two British teams led by Eddington took advantage of a solar eclipse to measure the deviation of a beam of light emitted by a star when it travels through the the gravitational field of the Sun. Separate observations were made with three different instruments; Einstein's prediction was confirmed by two of the three sets of measurements but not by the third; thus, the question could not be considered as completely settled[5]. During subsequent decades, astronomers took advantage of each total eclipse to repeat the measurement and obtained rather conflicting results. After World War II similar observations became possible with radiotelescopes which had the advantage of being independent of the occurrence of eclipses. Each measurement had only a low precision but by repeating them for hundreds of stars it was possible to improve the accuracy. In the 1990s very accurate atomic clocks were put aboard spacecrafts and provided other tests of general relativity apart from the deviation of a beam of light. Finally, in the early 2000s several huge facilities were set up in different countries in order to track the gravitational waves which are predicted by Einstein's theory but have never been observed yet. In short, for almost a century the predictions of general relativity have been tested and retested unremittingly.

On the contrary, social scientists do not expect to find laws of permanent and universal validity. As a matter of fact, the very idea that there can be universal laws is opposed by many social scientists. As a result, only limited time and efforts are devoted to making accurate measurements. Why should one bother to improve the accuracy of a law if one knows in advance that its validity will not outlast a couple of decades?

What is the position of social scientists on the question of bonds and interactions which is the topic of this book? First of all, one can remark that the situation is not at all the same as in physics. As one knows, the existence of molecules and the role of intermolecular bonds remained uncertain until the end of the nineteenth century. It is only after World War I that the strength of molecular interactions could be measured reliably. In contrast there can be little doubt that interpersonal relations exist and play a role in social phenomena. So far, however, we are unable to evaluate their strength. Why is it so difficult to gage the strength of interpersonal bonds? In a subsequent chapter we argue that it is the level of "noise" which is the main obstacle. Every person has many different roles, being simultaneously a husband or wife, a citizen, a consumer, a member of a religious community and so on and so forth. When one tries to focus on only one of these facets, the other interactions are nevertheless present and act as perturbing factors which, for the sake of brevity, we summarize under the term of "noise". In the study of social phenomena one of the main challenges is to improve the signal to noise ratio. Two subsequent chapters are devoted to this question.

The present study contains few theoretical models; this is intentional and deserves an explanation. One should keep in mind that there is a fundamental difference between model building in physics and model building in the social sciences. In physics there are several fundamental principles, such as Newton's law, the first, second and third principles of thermodynamics, the conservation of energy,

[4]This is what Harvard sociologist Stanley Lieberson calls "making the number count" (for more details see Lieberson (1985).

[5]Newtonian mechanics also predicted a deviation but of a different magnitude; therefore it is essential to measure the deviation with high accuracy.

of momentum, of angular momentum, etc. Any model must be consistent with these principles which means that model building is highly constrained and circumscribed. As a result, any model which in addition is also consistent with experimental evidence will be a meaningful model. In the social sciences there are almost no basic principles. Consequently, it is possible to build a great variety of models. As an illustration, one can mention that there are at least three different strands of stock market models. Some are based on a competition between informed investors and so-called "noise traders"; others are based on game theory, a third group relies on extreme value theory; one could mention several other varieties. Needless to say, all these models are able to explain the "stylized empirical behavior" of share prices. In this book we rather rely on what can be called *regularity models*. The notion can be explained by way of a simple illustration. Suppose that I wish to predict the rising time of the Sun. If on Monday I see it rise at 6:00, on Tuesday at 6:05, on Wednesday at 6:10, it will be natural to expect it to rise at 6:15 on Thursday and at 6:20 on Friday. This example may seem trivial but it can be complicated easily. Suppose that during the weekend I leave Paris to visit a friend in Brest, 600 kilometers to the west; once in Brest, the prediction for sunrise time will prove incorrect by at least 20 minutes which suggests that the initial model was too rudimentary. Furthermore, the model will also prove incorrect if one tries to use it on a time scale of several months. Thus, step by step, one will be able to improve the initial model. Many fields of physics in which there are no simple laws are organized in this way. For instance, Bernoulli's theorem serves as a *regularity model* in hydrodynamics in the sense that it "explains" several effects (e.g. the Venturi effect, the lift of an airfoil, the velocity of water exiting through a hole at the bottom of a tank, etc.) albeit with rather poor accuracy. As the standard Bernoulli formula does not take into account viscosity or turbulence it can serve only as a rough approximation. In each case, if one wants an accurate description, the Bernoulli model must be improved in several respects.

Writing this book has been an exhilarating journey in the course of which we have roamed through several social phenomena, various historical periods and many databases. In some places, we may have erred. That is almost inevitable if one considers the diversity of the data that needed to be processed. We welcome in advance any notification of possible errors or omissions. Few readers will probably read this book from cover to cover. This is why most of the chapters have been written in a way which makes them readable independently from the others[6]; in particular, some basic definitions and arguments have been purposely repeated in different places whenever they were needed in order to make each chapter almost self-contained.

It is a pleasure at this point to thank the many people who provided encouragement, help, support and advice. Throughout this research, the quest for various sorts of data has been a permanent concern. Naturally, the Internet was of great help; yet many of the data that we needed were not available on line but were kindly sent to us by helpful researchers working in statistical institutes or documentation centers. Many thanks to Maureen Annets (Commonwealth War Graves Commission), Dan Bernhardson (National Board of Health and Welfare, Sweden), Charlotte Björkenstam (Socialstyrelsen, Stockholm), Anita Brock (Mortality Statistics, UK), Birgitta Chisena (Statistics Office, Sweden), Adela Clayton (Australian War Memorial), Eddy Dufournont (INALCO, Paris), Christine Hauchecorne and Gilbert Chambon (Interlibrary loan, University of Paris 6-7), Annick Horiuchi (Department of Japanese Studies, University of Paris 7), Dorthe Larsen (Statistics Office, Denmark), Wenhui Li (Bureau of Vital Statistics, New York City Department of Health), Frida Lundgren (National Board of Health and Welfare, Sweden), Ron Orwin (British Commonwealth Occupation Force Executive Council of Australia), Gunvor Østevold (Statistics Office, Norway), Kenneth Schlessinger (National Archives

[6]Naturally, there are in fact many connections between the different chapters particularly between the chapters in part I and those in part II and III; part I sets the methodological guidelines which will be put to use in the two following parts.

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Through its physics publisher, Simon Capelin, Cambridge University Press played a pioneering role in the development of econophysics. As is the case for any new field, the first studies and publications were essential[7]and the collaboration between their authors and the publisher was instrumental in shaping and delimiting the new field. Since the early times of the mid-1990s the field has mellowed and its perspective has broadened. If the "physical approach" indeed opens a new frontier in the social sciences, there is no reason to confine it to financial analysis or to economic issues[8]. It is this challenge which lead to the writing of the present book. Once again as in former occasions, the contacts I have had with Simon have been a source of inspiration and I am most appreciative for his insight, perceptiveness and vision.

It is perhaps not surprising that the author of a book about social links is particularly aware of his debt to many unknown people whose activity and efforts permitted the fulfillment of this work. Reliable postal services, efficient electric utilities, convenient public transportation facilities and many other amenities were essential in the completion of this project. I express my deep gratitude to all these people and would like to extend special thanks to the drivers of the subwayline number 10 (Gare d'Austerlitz-Pont de Sèvres) which I took several times a week to go from my university to the

[7]It can be recalled that the first book to appear in this field was *An Introduction to Econophysics* by Rosario Mantegna and Eugene Stanley; it was published by Cambridge University Press in 2000.

[8]In an earlier publication (Roehner 2002c, chapter 3) we made the point that most economic problems ultimately are conditioned by sociological phenomena.

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Bertrand Roehner

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