PATTERNS OF SPECULATION

A Study in Observational Econophysics

BERTRAND M. ROEHNER

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Why econophysics?

Johann Gregor Mendel was born in Hyncice, in what is now the Czech Republic, on July 22, 1822. After studying science at Vienna (1851–1853), he became Abbot at Brno (1868). The question of how traits were passed from one generation to the next was at that time extensively investigated by several scientists, but with fairly inconclusive results. Unlike others Mendel studied only one trait at a time and he studied several generations instead of just two or three. He also managed to set apart accidental factors, such as the influence of foreign pollen. It is estimated that in the course of his investigation he observed about 28,000 peas, a figure which attests to the thoroughness of his investigation. He also devoted much time to meteorological observations; in addition to his two celebrated papers on hybridization he wrote nine articles on meteorological questions. This part of his activity is less well known because it did not lead to path-breaking discoveries, but it is interesting to observe that it continued a well-established tradition. Before him several other great scientists, such as Kepler (1571–1630), Descartes (1596–1650), or Lavoisier (1743–1794), had devoted a substantial part of their scientific activity to meteorological studies, without, however, being able to make significant inroads. This short account of Mendel's accomplishments encapsulates several of the themes that we develop in this chapter, such as the emphasis on thorough and systematic experimental work or the classification of scientific problems according to their degree of complexity.

As one knows the term econophysics designates the investigation of economic problems by physicists. It became a recognized field in physics around the mid 1990s when some physical journals began to publish economics studies. The word "econophysics" is a neologism which was coined in 1997 by Eugene Stanley on the pattern of "neurophysics" or "biophysics." However, in contrast to biophysics, which has a fairly clear justification as the study of the physical phenomena (such as for instance osmosis) which play a role in biology, the rationale for a marriage between physics and economics is less obvious. It is the role of this chapter to clear up that point. But, before coming to that, we must discuss two alleged (but nevertheless often mentioned) justifications.

The first one is that some theories developed to deal with complex systems in physics can possibly be applied to economic systems as well. This idea is not new; after all the mathematical framework of the theory of general equilibrium developed by Walras and his followers was largely borrowed from classical mechanics. However, in a general way the idea that a theory can be developed independently of observation seems weird and in any case is completely at variance with physical thinking. The theory of general equilibrium is no exception; it has led to an elaborate formalism which has very few points of contact with observation.

The second justification is the claim that because of their mathematical ability theoretical physicists are in a good position to build economic models. This may have been true before the 1950s when economic teaching was still essentially qualitative and non-mathematical. At that time, the only way to obtain a good mathematical foundation was to graduate as an engineer or a physicist. Several great economists, such as V. Pareto (1848–1925) or M. Allais (Nobel laureate in 1988), were indeed trained as scientists. However, in the second half of the twentieth century, there was an explosion in the number of journals and papers in mathematical economics (see in this respect Roehner 1997, 10–11). One needs only to leaf through a journal such as *Econometrica* to realize that economists are hardly in want of mathematical sophistication.

In this chapter we take a completely different position and argue that what hinders the development of economics is not the inadequacy of the theoretical framework but rather the difficulty of conducting satisfactory observations. To begin with, we trace the elements which in physics permitted a fruitful interaction between theory and observation. In the first two sections we take as our starting point Newton's apple paradigm.

1 Newton's apple paradigm revisited

"[After dining with Newton in Kensington on April 15, 1726] we went into the garden and drank tea under shade of some apple-trees. Amidst other discourses he told me he was just in the same situation as when formerly the notion of gravitation came into his mind. It was occasioned by the fall of an apple as he sat in contemplative mood. Why should that apple always descend perpendicularly to the ground thought he to himself. Why should it not go sideways or upwards but constantly to the earth centre?" This is how William Stukeley (1752) recounts the celebrated anecdote about Newton's apple.

1.1 Newton's apple

Nowadays we are so accustomed to associating the fall of an apple with the concept of gravitation that it is easy to overlook many important aspects of the question. For instance, the very fact that Newton concentrated his attention on the trajectory of the apple is non-trivial. As a matter of fact, if we look at that phenomenon with the eyes of someone such as Descartes or Galileo, who both lived before Newton, we can observe three phases (fig. 1.1):

- The apple breaks loose from the branch possibly because of a sudden gust of wind.
- The apple falls.
- The apple hits the ground.

Of these three phases it is the second which captured Newton's attention, but it is in fact the least spectacular. The fall occurs without a sound and has no incidence on the apple. However during the two other phases, the apple undergoes a visible

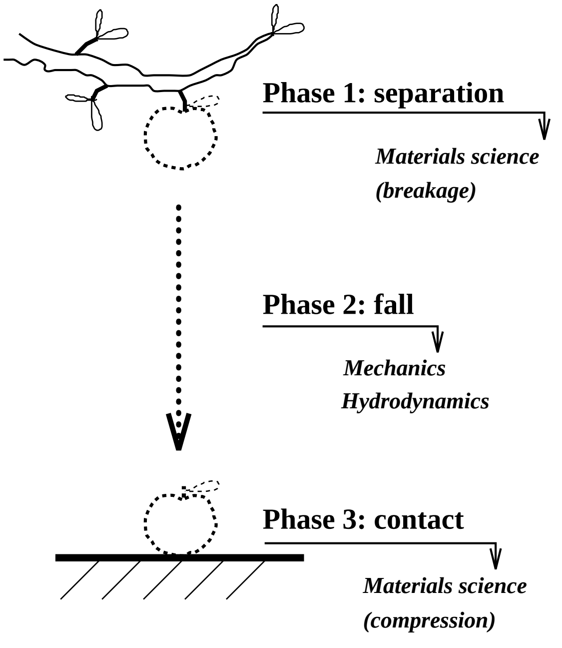

Fig. 1.1. Fall of an apple
Notes: There are (at least) three phases in the fall of an apple, each of which pertains to a different branch of physics. Historically, it was the investigation of phase 2 which proved of paramount importance by leading Newton to his ground-breaking theory of gravitation. In terms of complexity phase 2 is a two-body problem while the two other phases correspond to N-body problems. Focusing on that phase constituted an important step in Newton's discovery.

transformation. For instance, the rupture of the link between the stem (the peduncle in botanical terms) and the branch is by no means a trivial phenomenon. Furthermore the fact that the apple may be bruised when it hits the ground is of interest to the gardener for it is well known that a bruised apple cannot be stored for a long time.

Unlike history, science is not concerned with single events; single events can only be described. In order to discover regularities one must consider a *collection of similar events*. Of course it is the word *similar* which is both crucial and difficult to define. For the purpose of illustration let us consider the collection of events which can be considered in relation to each of the phases of the fall of an apple. Needless to say, these clusters of events are not defined univocally; they completely depend upon the phenomenon that one wants to study.

1 *Separation from the tree* If one wants to study the influence of the diameter or length of the peduncle one may consider a cluster of events, comprising the fall of cherries, plums, hazelnuts, and so on. This kind of study would pave the way for the science of breaking away of bodies, which nowadays is a subfield of the science of materials. As a matter of fact, three of the four celebrated dialogues by Galileo (1730) are concerned with that question. However, for reasons to be developed subsequently, Galileo was far less successful in these studies than in the dialogue which he devoted to mechanics.
2 *Fall of the apple* If one wants to study the influence on the fall of the density of the apple, a cluster of similar events would include the fall of chestnuts, figs, lemons, and so on. However these cases cover a fairly narrow density interval, and in order to broaden that interval one may also consider the fall of leaves, hailstones, or cannon balls. As we know, for all these items (with the exception of the leaves) the dynamics of the fall is more or less the same. A careful analysis would show that the $z = (1/2)gt^2$ regularity is better respected for items which are spherical, dense, and smooth, for in this case air resistance can be almost neglected. However if one were to consider the fall of various items in water, wine, or oil, this would open a completely different area of research and eventually lead to the creation of fluid dynamics.
3 *Landing of the apple* If one wants to study the way the fruit is affected when it hits the ground, a cluster of similar events would consist in observing how nuts, oranges, pears, peaches, or tomatoes are damaged when they hit the ground. Like the first phase, this phenomenon is connected with a field nowadays known as materials science.

In short, depending on the phases and factors that one decides to consider, a fairly simple observation like the fall of an apple can lead to studies in what we now know to be different fields of physics. Before we apply the apple paradigm to economic systems, let us come back to Newton. As one knows, his genial intuition was to include the Moon into a cluster of events similar to those of the fall of an apple. This was a brilliant generalization for, at first sight, the Moon seems to be of a quite different nature to that of an apple. A further generalization was made two centuries later by Einstein, when he included a beam of light into the cluster of falling bodies. The expedition led by Eddington during a total eclipse on Principle Island (West Africa) confirmed that, as predicted by the theory of general relativity, the light coming from stars just beyond the eclipsed solar disk was attracted by the gravitational field of the Sun.

1.2 An economic parallel

To many readers our discussion regarding Newton's apple may perhaps have sounded fairly trivial. However, by considering an economic analog, it will soon be discovered that the questions that it raised are at the heart of the problem. Suppose that on a particular Thursday, late in the afternoon, the American Department of Commerce releases inflation figures which turn out to be higher than were expected by the market, say 3.5 percent (in annual rate) instead of 1.5 percent. The next morning the Dow Jones industrials lose 5 percent right at the beginning of the session; fortunately in the afternoon the index regains 3 percent, thus limiting the daily fall to 2 percent. This is a fairly simple event but, as in the case of Newton's apple, one can distinguish different phases.

1. There is the reception of the information. The bad inflation figure comes to the attention of investors through various information means (Reuters headlines, internet, and so on), but it is very likely that interpersonal communication between analysts at various banks and financial institutions plays a critical role in the way the information is eventually interpreted. One can, for instance, imagine that the decision to sell taken by a few stock wizards induces other investors to follow suit.
2. On Friday morning before the opening hour the specialists who are in charge of the 30 stocks composing the DJI discover the level of selling orders that have been sent in during the night. In order to balance sales and purchases they have to set prices which are 5 percent below the previous day's closing prices.
3. Investors who have bought options (either to sell or to buy) over previous days (or weeks) were caught off guard by the unexpected inflation figure. The expiration day of many options is usually Friday at the end of the session, and, in order to improve their position on the option market, the option holders bought heavily in the last hour of the session.

More detailed explanations concerning the organization of stock markets will be given in subsequent chapters, but at this stage it is enough to realize that a certain trigger factor (the announcement of the inflation figure) produces a given result (the fall of the DJI) through a chain of mechanisms each of which represents a fairly complex phenomenon in itself. Phase 1 concerns the diffusion of news amongst a group of people. A cluster of similar events could include the diffusion of other unanticipated news, such as the assassination of Martin Luther King (1968) or the invasion of Kuwait by Iraq (1990), although these are more sociological problems than economic. Phase 2 concerns the procedure of price fixing: to establish, given a set of buying and selling orders, the “best” equilibrium price. A cluster of similar events would include price fixing episodes in other markets, such as commodity markets. Phase 3 concerns the interaction between option and stock markets. A cluster of similar events would include other episodes where stocks and options prices tend to move in opposite directions.

Earlier we saw that the various phases could be linked to different branches of physics. Do we have a similar situation above? As already observed the question raised by phase 1 appertains to sociology rather than economics, and it seems so far to have received very limited attention from economists. The issue of price fixing is a central problem in economics; in the present case, however, one is not in a favorable position because the data about the amount of selling or buying orders would not have been made public. The question raised by phase 3 is perhaps the only one for which satisfactory empirical evidence would be available; nevertheless, to our best knowledge such an investigation has not yet been performed in a systematic way.

By comparison with the case of the fall of an apple, we are in a less favorable situation. Whereas each phase could be linked to a well-defined branch of physics, here there is no organized body of knowledge that one can draw upon. Any investigations which have been devoted to the above issues are not of much help because: (i) they are scattered in various journals and therefore difficult to locate; (ii) they are cumbersome to use because, usually, they do not deal with a single and well-defined issue, but rather with compound and multifaceted problems. Whereas in physics complex phenomena are routinely decomposed into simpler components, each of which is well documented in various physical handbooks, in economics decomposing a multifaceted phenomenon into simpler components (fig. 1.2) is far from being a common approach. In the next section we discuss some historical factors which can explain why physics and economics developed in different ways.

2 Simple phenomena first

“Why, when left in the sun, does ice not soften like butter or wax? Why does the volume of water increase when it is changed into ice? Why is it possible by using salt to make water freeze in summer time?” These are some of the questions raised by R. Descartes in 1637 in his *Discourse on Method* (1824, my translation). These are difficult problems, and even nowadays physics is unable to propose simple explanations for these phenomena. In the methodological part of this work Descartes recommended to decompose every problem into as many parts as were required to solve it. However, this excellent rule was of little help because, as will be explained, the problems that he considered are intrinsically complicated. As a result one cannot be surprised by the fact that the answers provided by Descartes were highly

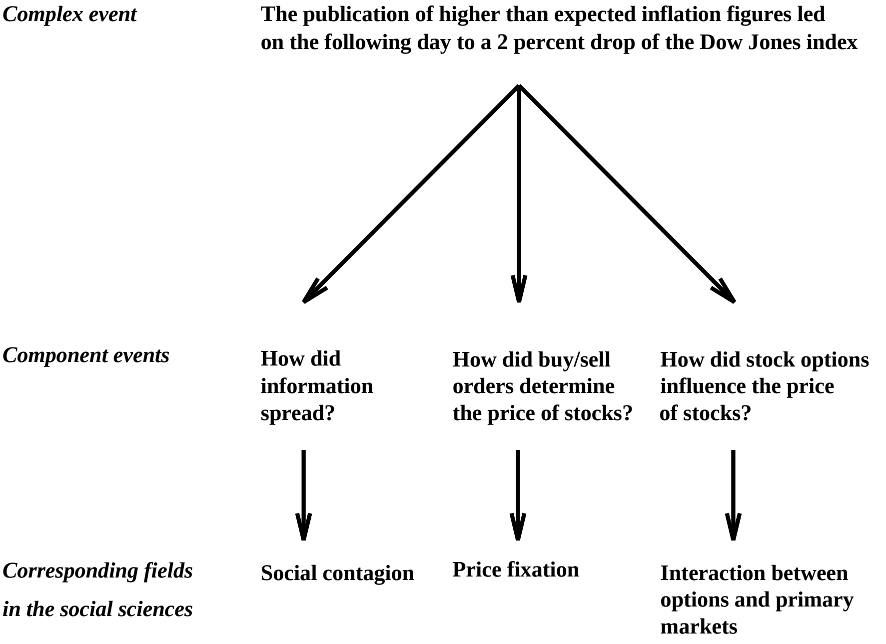

Fig. 1.2. Fall of the Dow Jones index
Notes: At least three different phenomena can be distinguished in the events that brought about a fall in the Dow Jones index. But in contrast to the fall of an apple the specific branches of economics that would treat these different phenomena are not well developed yet.

unsatisfactory.The only phenomena for which he provided appropriate models were those concerned with the study of refraction and the explanation of the rainbow; we will soon understand why. Half a century later, Newton undoubtedly was more successful and one of the main reasons for that is the fact that by concentrating his investigations on optics and mechanics he set himself more reachable goals. The fall of an apple for instance is what physicists call a two-body problem for it involves only two interacting items, namely the apple and the earth. In this section we understand this notion in a somewhat extended sense. For instance, when a beam of light goes through a prism we will still say that it is a two-body phenomenon because it involves only two items, namely the light and the prism. Somehow in the same spirit, Mendel's experiment with peas can be called a two-body phenomenon because it involved only two types (smooth versus wrinkled) of peas.

2.1 Two-body problems

A little reflection shows that most of the problems that physics and biology were able to solve in the nineteenth and early twentieth centuries were of the two-body type.

Several illustrative examples can be mentioned (see also table 1.1(a)): the Sun–Mars system studied by Kepler and Newton; the proton–electron system of the hydrogen atom; the interaction between two heat reservoirs at different temperatures (second law of thermodynamics); the interaction between light and a reflecting or transparent medium (geometrical optics); the Sun–Mercury system studied by Schwarzschild in the framework of General Relativity theory.

One could be surprised not to find any economic examples in table 1.1(a). As one knows, two-body problems were extensively studied in economics: in microeconomics this led to two-market or two-company models, in macroeconomics to two-sector or two-country models. Why then did these models not play a role similar to the two-body problem in celestial mechanics? In contrast to what happened in physics these two-body models could *not* be confronted with empirical evidence because no real economic systems matched the two-body assumptions even in an approximate way. It is true that in physics the two-body models are only approximations, but in the case of the Sun–Mars problem studied by Kepler and Newton the approximation holds with an accuracy better than 5 percent. In economics exogenous factors are as a rule of the same order of magnitude as endogenous effects. One is confronted with a similar situation in meteorology, in the sense that it is almost impossible to isolate two-body systems which can be studied independently of their environment.

Perhaps some simple economies that existed in the mid nineteenth century in parts of Africa and in some Pacific Islands could have provided closer two-body system approximations. However, unfortunately, to the best of my knowledge, no comprehensive statistical data are available for such societies. In the same line of thought, ant colonies constitute examples of fairly simple economic systems and in these cases it would be possible to generate reliable data by monitoring ant colonies in the laboratory. For instance, colonies of harvesting or gardening ants (Weber 1972) could provide a model of a two-sector economy. Of course it would be a non-monetary economy for which one would have to reason in terms of working time and material output. Such an avenue of research will probably be explored in the future, but at present no data of this sort seem to be available.

2.2 Complexity classification

Table 1.1(b) lists problems in physics, biology, or the social sciences by order of increasing complexity. The Ising model appears at the very beginning of the list of *N*-body problems for two obvious reasons: (i) it provides a fairly good description of the phenomenon of ferromagnetism and (ii) the analytical solution obtained by L. Onsager (1944) for a two-dimensional Ising model provided for the first time a spectacular illustration of the fact that a short-range interaction restricted to nearest neighbors could generate unexpected effects, such as spontaneous magnetization – below a critical temperature the spins align themselves and collectively generate a non-zero magnetic moment. From the perspective of economics this example is of great interest because it proves that a simple interaction between agents can bring about non-trivial collective phenomena. Table 1.1(b) shows that the basic problem of macroeconomics, namely the interaction between N sectors of an economy is mathematically of a level of difficulty which is far above that of the two-dimensional Ising model. Indeed, whereas the Ising model involves only one sort of interaction, an N-sector economy involves a variety of interactions. What makes things worse is the fact that these interactions are usually time dependent. For equity markets there are also different kinds of interaction: banks, pension funds, insurance companies, or equity option speculators do not have the same goals nor the same reaction times.

Table 1.1(b) can help us to better understand some of the observations that we made earlier in this chapter: (i) Let us first consider the questions raised by Descartes that we mentioned at the beginning of this section. The question of water versus ice volume is of complexity $C2$; the question of butter versus ice is at least of level $C2$ and probably of level $C4$ if butter contains several kinds of molecules which are relevant. One understands why Descartes was more successful in optics which is of level $C1$. (ii) The gravitational interaction between the earth and a falling body belongs to class $C1$, whereas materials science belongs to class $C2$; thus one can understand why Galileo was able to unravel some of the laws that govern the movement of a falling body but was less successful in his studies regarding the coherence of solids. (iii) As we pointed out at the beginning of this chapter, many brilliant scientists such as Kepler, Lavoisier, or Mendel made extensive studies in meteorology without, however, being able to offer any decisive and ground-breaking contribution; this becomes understandable on account of the fact that meteorology is of complexity level $C4$. A complementary complexity criterion is given in table 1.2.

2.3 The role of time: Simon's bowl metaphor

Among the economists of the 1960s and 1970s, the work of H. Simon (Nobel prize laureate in 1978) stands somewhat apart. His approach to economics was largely influenced by system theory, and it is therefore not surprising that he gave much attention to the question of complexity (Simon 1959, 1962). He proposed the following example in order to illustrate the fact that dynamical problems are inherently far more difficult to study than systems in equilibrium. This is a distinction that we have not made so far and which complements the results in tables 1.1(a),(b). Simon's (1959) argument goes as follows: Suppose we pour some viscous liquid (molasses) into a bowl of very irregular shape, what would we need in order to make a theory

Table 1.1(a). *Two-body problems in physics and biology*

Interaction between:	Century	Scientists
Earth–falling body	16th	Galileo (1564–1642)
Light–glass	17th	Snell (1591–1626), Descartes (1596–1650), Newton (1642–1727)
Sun–Mars	17th	Kepler (1571–1630), Newton
Static gas–container	17th	Boyle (1627–1691)
Flowing fluid–pipe	18th	Bernoulli (1700–1782)
Two heat reservoirs	19th	Carnot (1796–1832)
Liver–pancreas	19th	Bernard (1813–1878)
Two alleles of a gene	19th	Mendel (1822–1884)
Proton–electron	20th	Bohr (1885–1962)
Sun–Mercury	20th	Schwarzschild (1873–1916)

Notes: The scientists' names are given in order to specify to which phenomenon and law we refer.

of the form the molasses would take in the bowl? If the bowl is held motionless and if we want only to predict behavior in equilibrium, the single essential assumption would be that under the force of gravity the molasses would minimize the height of its center of gravity. However, if we want to know the behavior before equilibrium is reached, prediction would require much more information about the properties of molasses, such as for instance their viscosity, density, and so on.

How should Simon's metaphor be understood from the perspective of the classification in table 1.1(b)? Molasses, like Descartes' butter, would belong to level $C2$ if there is only one preponderant interaction or $C4$ if there are several competing interactions. Yet, as pointed out by Simon, the equilibrium problem in a gravitational field is rather a two-body problem. The reason is easy to understand; in equilibrium the interaction between the molecules does not play any role, which means that the bowl of molasses is not fundamentally different from Newton's apple. More specifically the general laws for a fluid in equilibrium also apply to molasses. Alternatively, in a dynamic situation the interactions play a key role and the problem is far more complicated.

2.4 Simple aspects of complex systems

Table 1.1(b) seems to convey a pessimistic view regarding the prospects for economic analysis. Is the situation really hopeless? Not at all. A parallel with meteorology can help us to understand why. Like economics meteorology is of complexity level $C4$; as a matter of fact obtaining an accurate model of the interaction of air and water masses on a world-wide basis is an almost impossible task. Arguments

Table 1.1(b). *Problems of increasing complexity in physics, biology and the social sciences*

Level of complexity	Problem
$C1$	*Two-body problems (see table 1.1(a))*
$C2$	*N-identical body problems with interaction between nearest neighbors* Interaction between N spins (ferromagnetism Ising model) Interaction between nucleons in complex nuclei Interaction within a population of bacteria belonging to the same species Interaction between N grain markets
$C3$	*N-identical body problems with a long-range interaction* Interaction between N neurons of same type Interaction between N similar investors in equity markets
$C4$	*N-non identical body problems (several interactions)* Interaction of air and water masses (meteorology) Interaction between N genes (morphogenesis) Interaction between different kinds of neurons in the brain Interaction between N words (linguistics) Interactions in a colony of bees or ants Interaction between N sectors of an economy (macroeconomics) Interaction between N national economies (international trade) Interaction between various kinds of investors in equity markets Interaction between states (international relations)

Notes: In the present classification complexity is understood from a mathematical perspective. What gives some confidence in the pertinence of this classification is the fact that it is corroborated by the historical advancement of science: the understanding of systems of low complexity historically preceded the comprehension of systems belonging to higher complexity levels. For complex systems there are richer forms of collective behavior, but, alternatively, it is more difficult to get analytical results which clearly state the conditions under which these forms of collective behavior will occur. It should be noted that, apart from the type of interaction, there is another essential difference between, for instance, a complex nucleus and an equity market; by contrast with the nucleus for which the properties of the interaction are experimentally well known, for equity markets the interactions between various investors are basically unknown.

about the chaotic nature of these phenomena may even suggest that this objective is altogether unreachable. Nevertheless there are many specific meteorological *mechanisms* which can be understood fairly simply, for instance the fact that in the northern hemisphere wind directions are deflected to the right with respect to gradient lines of the pressure field is known as the Coriolis effect. As it happens the Coriolis force is a standard phenomenon in classical mechanics; but, even without any prior knowledge (that is to say leaving aside for a moment what we know from laboratory experiments), it can also be discovered by carefully analyzing wind

Table 1.2. *An objective measure of biological complexity*

Organism	Fifty percent lethal dose of X-rays [rad]
Viruses	100,000
Bacteria	3,000
Mamalian cells	100

Notes: Table 1.1(b) is of little usefulness if one wants to compare the complexity of various biological organisms for all of them would belong to the *C*4 complexity level. The criterion used in this table is based on the assumption that more complex systems are more sensitive to disorders brought about by radiations. The proportion of surviving organisms is a decreasing exponential function of the dose: the 50 percent lethal dose corresponds to the survival of one half of the population.
Source: Encyclopédie Internationale des Sciences et des Techniques (Paris 1973).

directions at spatially separated meteorological stations. The fact that wind directions are deflected to the right at any time and anywhere in the northern hemisphere suggests that this effect must be due to a basic permanent factor (such as the rotation of the earth). Naturally such an analysis will by no means be straightforward because there are many disturbing factors (thermal effects, mountains, and so on) which must be discarded before the main effect can be isolated. In short, even though the construction of a global theory is a very difficult challenge, it is possible to discover regularities which provide at least partial understanding.

We believe that the situation is very much the same in economics: although the construction of a global model of the world economy may be out of reach, it is possible to build fairly simple models of specific economic phenomena. Such models provide partial understanding but do not permit global prediction, and this is why this objective should be set aside at least temporarily. Such a view was similarly expressed by Schumpeter (1933) in the first issue of *Econometrica*: "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."

The following section offers some practical hints for the search of regularities.

3 From plausible reasons to regularities

Our objective is to generalize the rules that guide experimental investigation to cases where no experiments can be performed and one has to rely on collecting observations. Apart from economics, this discussion also concerns other observational sciences, such as astrophysics, geodynamics, or meteorology. The main difference between these sciences and economics is that the former can rely on physical laws that were discovered independently whereas the basic laws that govern the social behavior of economic agents are still unknown. To begin with we consider a very simple example.

3.1 The pot of yoghurt paradigm

Suppose you spend your vacation in a mountain resort at an altitude of 1,000 meters. You take a pot of yoghurt from the fridge and observe that the thin metallic cover that forms the lid has a convex shape (i.e. the center is higher than the rim). Since you have never observed this before you wonder what the explanation may be. A number of possible explanations can be tentatively proposed; one can mention the following for instance:

1 Some kind of fermentation in the yoghurt has led to the production of gas which has increased the pressure inside.
2 The yoghurt was upside down in the truck that brought it from the dairy to the grocery; this gave to the metallic cover a convex shape which it retained.
3 The engine of the refrigerator contains magnetic parts which exerted a force on the metallic cover.
4 When the pot was sealed at the diary two or three days ago the atmospheric pressure was higher. As the pressure fell the air contained in the pot provoked the convex shape.
5 At an altitude of 1,000 meters the atmospheric pressure is lower than in the valley where the dairy is located. As the truck climbed the mountain side, outside pressure decreased and the air contained in the pot expanded provoking the convex shape.

Before we begin to discuss these different explanations an important comment is in order. In previous sections of this chapter we emphasized that a single event cannot be investigated scientifically, it can only be described; only clusters of events can be scientifically explained. As a matter of fact all the previous explanations are plausible. In order to decide which one is correct, additional evidence must be collected. For instance, one could look at the milk bottles. If their lids have the same shape this would exclude the first explanation (unless one assumes that there was a similar fermentation for the milk, an assumption which although unlikely cannot be completely ruled out). If the convex shape can already be observed in the grocery this would reject the third explanation (unless one assumes that the refrigerator in the grocery or in the truck also generates a magnetic field); of course if one can determine that the pot has an aluminum cover the explanation would definitely be rejected. By examining the aspect of the cover it is perhaps possible to determine whether it was upside down in the truck (or at the dairy). In short, it may be assumed that by a number of additional observations one is able to eliminate (at a reasonable level of confidence) all explanations except the last two.

As one knows each of these phenomena may actually play a role and it is not a simple matter to decide which one is preponderant. The average pressure difference between sea level and an altitude of 1,000 meters is about 110 hectopascal (*Quid* 1997, 107). However the pressure variation between an anti-cyclone and a depression is of the order of 50 hectopascal. But this does not necessarily mean that effect number 5 is preponderant, for the dairy is certainly not located at sea level; if it is located in the valley at an altitude of 600 meters the two effects can be of the same magnitude. If the location of the dairy can be known this will of course facilitate the solution of the problem. If however it cannot be known (which is a fairly common situation in a field such as economics where many data remain confidential) one could try to obviate that lack of information by carrying out additional observations. For instance one could repeat the same experiment of buying yoghurt jars over several days in a row; if the date on which the yoghurt was produced is indicated on the pot the contribution of effect number 5 can be derived (at least in a relative way) from daily records of atmospheric pressure. Usually however the production date is not indicated and one must be content with a reasonable guess, for instance one week prior to the "best before" date.

The reader may perhaps think that an observation regarding a pot of yoghurt hardly deserved such a detailed discussion. In the following paragraph we will give some more academic examples. In any case the previous analysis illustrates and emphasizes two points which are of great importance in economic analysis: (i) It is impossible to reach any definite conclusion by considering a single observation; in order to be able to observe the phenomenon under different circumstances one needs to analyze a collection of similar events. Although this rule may sound fairly obvious to any physicist it is often forgotten in economic analysis as attested by the huge number of books which were devoted to the analysis of the crash of 1929 (a single event). (ii) In economics it is usually not possible to control or even to know all factors which may affect an observation. In many cases hard knowledge has to be replaced by an educated guess. As a result the confidence level of the proposed explanation is usually lower than in physics. However, by including more observations into the cluster of events, it is often possible to improve the level of confidence. For instance, by selecting a period of observation during which atmospheric pressure remained almost constant, it is possible to get rid of changes in atmospheric pressure. In short, by progressively extending the cluster of similar events under investigation, it is possible to converge toward a reliable model.[1]

[1] For the application of that approach to a comparison of the spatial distribution of prices in China and France, see Roehner and Shiue (2001).

3.2 Plausible causes versus scientific explanations

In scientific explanation one can distinguish three levels. The first level corresponds to enumerating plausible causes; the second consists in determining which of these causes actually played a role. This second level corresponds to what we call the search for regularities. The third level implies the construction of a theory that can account for a cluster of similar events. For the yoghurt example, the first level consisted in listing five plausible factors; the second level was reached when after a careful discussion we were able to prove that only two of these factors indeed played a role. The third level consists of proposing a quantitative theory that would explain not only the inflation of yoghurt jars but would also account for the deformation of orange juice cartons and other containers.

For the purpose of illustration let us consider a more dignified example, namely the much debated question of the disappearance of the dinosaurs. First of all it must be noted that since this is a single event it does not really admit a scientific explanation. One can list a number of plausible or real causes but it will never be possible to build and test a comprehensive theory. Among the plausible causes that are most often mentioned one can cite a change of climate, lack of food, gigantism, or the fall of a meteorite.[2] The second level of explanation would consist in identifying those factors which actually played a role. For instance if one found meteor craters corresponding to impacts that occurred at the beginning of the period when the population of dinosaurs began to decline, this would lend some credibility to that argument; although it does not really prove that there was indeed a link between the two events. For this purpose one would have to build a model which would quantitatively specify the expected changes in climate and vegetation. Needless to say such a model must then be tested on *all* large known meteor impacts; if the changes in the years following the impact are in agreement with the model, then one can proceed with additional confidence to apply it to the case of the dinosaurs.

It is now time to consider an economic example. In January 1979 a one-carat, flawless, gem diamond cost 20,000 dollars on the Antwerp market; in February 1980 the same diamond was worth 60,000 dollars; subsequently that price plummeted to 40,000 dollars in January 1981 and 20,000 dollars in January 1982 (Diamonds 1988, *The Economist*, Special Report No. 1128). What explanations did diamond experts put forward in order to explain such a sudden price peak? In 1988 an authoritative economic assessment of the past decade was made by the president of the Gemological Institute of America, a well-respected institution in the industry (Boyajian 1988). His explanation goes as follows. In 1976 Israel was a young but

[2] In the same spirit Lieberson (2000) lists a number of plausible reasons for the decline of dress hats; a very instructive exercise!

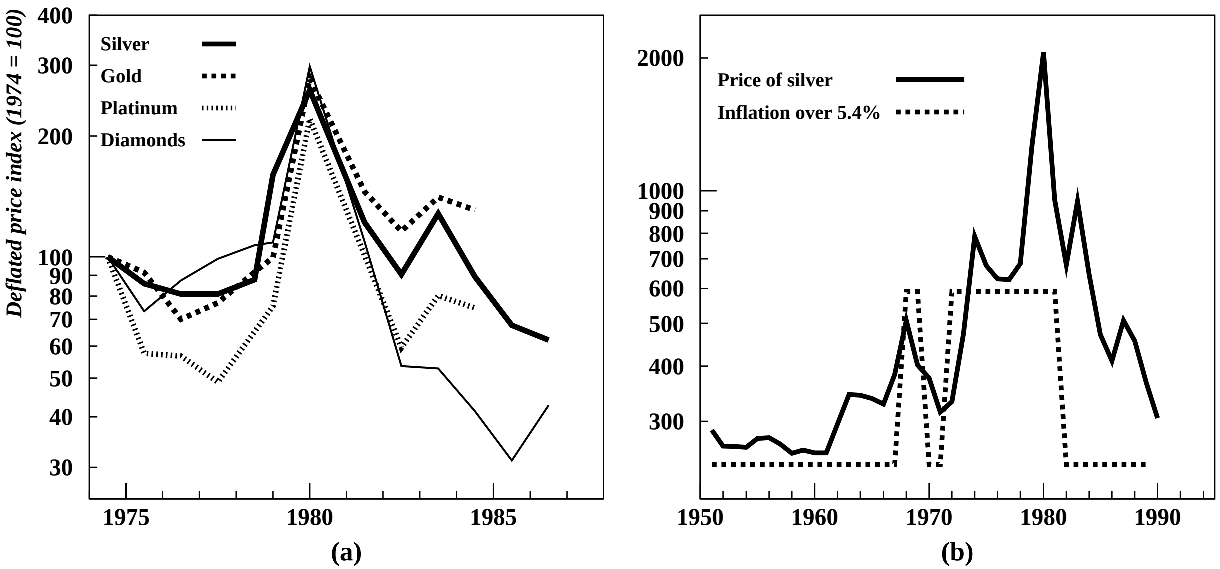

Fig. 1.3a. Price peaks for diamonds, gold, platinum and silver
Notes: Gold, platinum and silver prices are expressed in dollars per ounce troy; for diamonds the price is for a one-carat, G clarity, flawless diamond. The bubble and its collapse occurred almost simultaneously in the four markets. That coincidence contrasts with a rather weak correlation between the four prices in normal times; thus, between 1993 and 1998, the prices of gold and silver were almost uncorrelated. The prices of cobalt and palladium display a similar peak but have been omitted for the sake of clarity.
Sources: International Financial Statistics (International Monetary Fund 1979, 1991), *Journal des Finances* (October 26, 1978), *The Economist* (April 5, 1980), Diamonds 1988 *The Economist*, Chalmin (1999).

Fig. 1.3b. Deflated price of silver and inflation rate
Notes: Vertical scale: annual price of silver in New York expressed in 1980 cents per ounce troy; in terms of daily prices the maximum would be at a fairly high level (4,500 cents/ounce on January 8, 1980). The inflation rate refers to the US consumer price index; the dashed line represents a two-valued function which is equal to 1 when the inflation rate is over 5.4 percent and to 0 when it is below. The graph shows that the price peak was largely the result of a flight from inflation and that a 6 percent rate seems to be a critical level in that respect.
Sources: International Financial Statistics (International Monetary Fund 1979, 1991); Historical Statistics of the United States (1975).

rapidly growing diamond center. Anxious to promote the diamond trade which represented 40 percent of Israel's non-agricultural exports, the Israeli government supplied several banks with huge amounts of money at very low interest rates to be passed on to diamond manufacturers so they could build their inventories of rough diamonds. But because of the rapid increase in diamond prices many diamond cutters found it more profitable to hold their rough diamonds rather than to cut them. Thus, they created an apparent demand that really did not exist. Soon the speculative fever spread to Antwerp and New York, the two other main diamond centers. At first sight such an account sounds plausible. However, if one looks at it more closely it becomes clear that there are several loopholes in the argument. First, it assumes a rapid increase in diamond prices, which is precisely what one wants to explain; second, one may wonder why the speculative fever spread to Antwerp and New York where no low interest government loans were available. Third, the American and Japanese markets for polished diamonds represented at that time about 60 percent of the world market and therefore one would expect them to play a leading role. Fourth, one would like to know the total amount of the low interest loans made by the Israeli government to the cutters in order to compare it to diamond world sales.

These remarks already make the proposed explanation somewhat doubtful but the decisive point is the fact that the diamond price peak was by no means an isolated phenomenon. As a matter of fact cobalt, gold, platinum, palladium, and silver all experienced a huge price peak, which paralleled almost exactly the one for diamonds (fig. 1.3(a)). Accordingly, one can hardly accept an explanation which concerns only one of these goods; there must have been a factor which explains the other price peaks as well. That factor is the rate of inflation in western countries, which provoked purchases of all kinds of tangibles from precious metals to antiquarian books or postage-stamps (see fig. 1.3(b)). A more detailed analysis is to be found in a subsequent chapter.

In short we see that the scenario proposed by diamond experts was wide of the mark; the injection of capital into the Israeli diamond market cannot be disputed of course, but it had only a negligible impact on the diamond market. Needless to say, similar *ad hoc* explanations were proposed for the other price peaks as well. Thus, the price peak for silver is currently "explained" by the failed attempt of Nelson B. Hunt, a Texan billionaire, to corner the market. Numerous books and articles have developed that thesis; see for instance the article "The silver coup that failed" which appeared in the *Financial Times* (March 29, 1980) or the book by S. Fay (1982).

The previous examples are interesting in another respect. They show that there is a natural tendency to favor short-term, anecdotal evidence at the expense of structural, statistical explanations. Both the Israeli diamond episode and the Hunt silver story occurred in the year preceding the price peak and these anecdotes are of course intuitively more appealing than long-term structural causes, such as the role of inflation. Once again we see that it is only by considering a cluster of similar events that it is possible to get at the roots of the phenomenon.

The reader will perhaps think that we overdid the point by emphasizing the anecdotal character of the explanations put forward by economic experts. How can experts rely on such flimsy evidence? In order to judge for himself (herself) the skeptical reader can have a quick look at the headline news of major economic and financial news agencies, such as Reuters Business News, Reuters Securities, AP Financial, and so on; they can be found on several internet sites. He (she) will perhaps be surprised to see that there is a flood of qualitative statements, but very little global evidence; for instance such important pieces of information as the average price–earnings ratio of the NYSE (New York Stock Exchange) or NASDAQ, the number of bankruptcies in past quarters, the ratio of corporate bond downgrades to upgrades (an assessment of the financial situation of corporations) are hardly ever given.

3.3 Regularities

From a methodological perspective the strong emphasis econophysics has put on the search for regularities is probably one of its most important innovations. In contrast, for most economists a quantitative regularity is considered of no interest unless it can be interpreted in terms of agents' motivation and behavior and has a clearly defined theoretical status. In order to illustrate that difference in perspective let us consider an important result obtained by an econophysical team (Plerou *et al.* 1999). These authors analyzed a huge data base containing annual research and development expenditures (S) for science and engineering in 719 American universities. More specifically they studied the way in which the fluctuations in the growth rate $g(t) = \ln[S(t+1)/S(t)]$ depend on the size of $S(t)$. They have found that the standard deviation $\sigma(S)$ of the fluctuations is proportional to $1/S^{0.25}$. Two circumstances explain why this is a result of outstanding interest: (i) It is fairly robust with respect to the measure of size that is used, whether for instance the expenditure or the number of papers published. (ii) There is a similar law for the growth rate of firms, with an exponent which in this case is 0.17 instead of 0.25. Such a result can be considered as a first step toward a comprehensive theory of growth.

Only a few economists would share that opinion however. In their eyes the previous result has two major shortcomings: (i) it does not fit into any existing theory; (ii) it has no clear interpretation in terms of optimization and rational choice.

3.4 Circumstantial causes versus structural factors

We have already seen that economic experts tend to favor short-term circumstantial causes at the expense of long-term structural factors. Far from being specific to economics this tendency is in fact common to all social sciences, and for an obvious reason: short-term causes seem intuitively far more convincing that structural explanations. Here is a non-economic illustration. During the 1980s and 1990s there have been numerous clashes and even large-scale massacres in Burundi and Rwanda. For each of these episodes one can invoke numerous circumstantial causes, such as an attempted coup, the assassination of a prime minister, and so on. On the structural side one can notice that Burundi and Rwanda have the highest population density in Africa coupled with a high increase rate. In 1995 the density was about 250 people per square kilometer for Burundi and 310 for Rwanda as compared to 110 for Nigeria and 35 in South Africa (*Quid* 1997, 1056). Intuitive reasoning is unable to take into account such structural factors except as vague background cause. In order to assess the role played by these factors one needs a comprehensive quantitative model.

3.5 Models need accurate empirical targets

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

(Anna J. Schwartz (1995))

Nobody would doubt that experimental research is an essential part of physics. Economics, in contrast, does not encourage "experimental" research (quasi-experimental would of course be a more adequate term). The above citation by A. Schwartz describes fairly well this situation. The bias in favor of theoretical work is due partly to a trend that is common to different fields and partly to a tradition which is proper to economics. The first factor is related to the well-known fact that the productivity of a researcher, as measured by his (her) annual output of published papers, is much higher for theoretical work than for experimental research. But for economics this trend was strongly reinforced by its own tradition: in earlier centuries only few data were available and economists developed the habit of replacing genuine observations with "Gedanken" experiments. For instance, instead of observing the actual behavior of real estate investors, economists tried to imagine how, from a rational perspective, they *should* react. Unfortunately there is often a wide gap between expected and actual behavior. The neglect of empirical work was denounced by several great economists, such as M. Friedman,

C. Granger (1991), W. Leontief (1982, 1993), or A. Schwartz, but this did not reverse the trend. From its very beginnings econophysics recognized the importance of empirical research. Many empirical studies (several of them are discussed in subsequent chapters) which would never have found their way into economic journals appeared in physical journals. Over the next few years this should lead to the accumulation of a wealth of regularities and empirical knowledge which may provide the much needed guideposts and landmarks for the building of models and theories.

Why are such guideposts so indispensable? The answer can be illustrated by the following example. By 1999 no less than ten econophysical models were reported in the pioneering book by Mantegna and Stanley (2000) which were able to explain the main stochastic properties (e.g. rapidly decreasing auto-correlation or the fat tail of the distribution function) of stock price changes. To that number an equal number of models developed by economists or financial analysts should certainly be added. When more than 20 models are able to explain the main empirical features it is clear that the constraints are too lax and the target too big. Four centuries ago the situation was the same in astronomy: until Tycho Brahe's observations, the Ptolemy model was as acceptable as the Copernicus model.

4 Conclusion

The message of this chapter comprised three main points: it emphasized the crucial role of observation; it argued that major progress can come from the study of simple problems; and, finally, it insisted on the importance of comparative analysis.

4.1 The primacy of observation

Most of the Nobel prizes in physics have been awarded for experimental discoveries. Moreover, to the best of my knowledge, not a single one has been attributed for a theory which could not or had not been confronted with experimental evidence. The situation is completely different in economics. As a matter of fact several Nobel prizes have been awarded for work which remains completely theoretical. Just to mention three examples, one would in vain search for any statistical test in the works of P. Samuelson (Nobel prize in 1970), G. Debreu (Nobel prize in 1984), or M. Allais (Nobel prize in 1988). This striking contrast emphasizes the fact that observation and experimental evidence have a completely different status in physics and economics. It is true that (quasi-) experimental research in economics is more difficult to conduct than in physics, but this should rather encourage us to devote more time, energy and patience to such research.

4.2 "Modest goals"

Throughout its history, confronted as it was with the expectations of governments, traders and investors, economics has had a tendency to take up global problems and to develop predictive models. But such ambitious objectives diverted economists from the patient work of collecting and organizing empirical evidence, which would have permitted them to discover significant regularities. Once again a parallel with meteorology may be enlightening. In meteorology, as in economics, one of the main objectives is to make reliable forecasts; however this did not prevent meteorologists from establishing firm foundations before trying their hands at making forecasts. Thus, in the 1830s, the comparison of wind directions at several places uniformly spaced over a large area constituted one of the major tasks of comparative meteorology (also called synoptic meteorology). Such a study had no direct practical application in terms of forecasting ability, but it permitted the establishment of Coriolis law, which governs the movements of air and water masses at the surface of the earth, and paved the way for further progress. This is the procedure advocated by J. von Neumann and O. Morgenstern in the citation mentioned at the beginning of this book: to set oneself modest goals and to advance step by step from one clearly understood question to the next.

4.3 Clusters of events and comparative analysis

Taking Newton's apple paradigm as our starting point we emphasized that even such a simple event as the fall of an apple has in fact many different facets. In order to analyze it in a meaningful way one must first *decompose* it into simpler components and, when this has been done, try to conjecture which components correspond to "simple" phenomena. Once a specific phenomenon has been selected the real empirical investigation begins, which consists of collecting evidence about a cluster of similar events. By comparing the evidence from these events it becomes possible to determine which factors play a crucial role and which ones are merely incidental.

In the previous procedure the critical step of selecting the events to be investigated depends to a large extent on the criteria used to define the degree of complexity (or simplicity) of a system. In this chapter we proposed two main criteria: (i) the number of interactions between the elements composing the system; (ii) the status of the system with respect to time, that is to say whether or not the system can be considered in equilibrium.

The key idea that only a comparative analysis of a cluster of similar events can reveal meaningful regularities was illustrated through several examples. In particular we saw that the "explanations" put forward by experts are often no more than fanciful anecdotes. The approach delineated in this chapter will be applied repeatedly in subsequent chapters. But, before coming to that, we give in the next chapter some brief indications about the historical development of econophysics.