Part I

Econophysics

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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

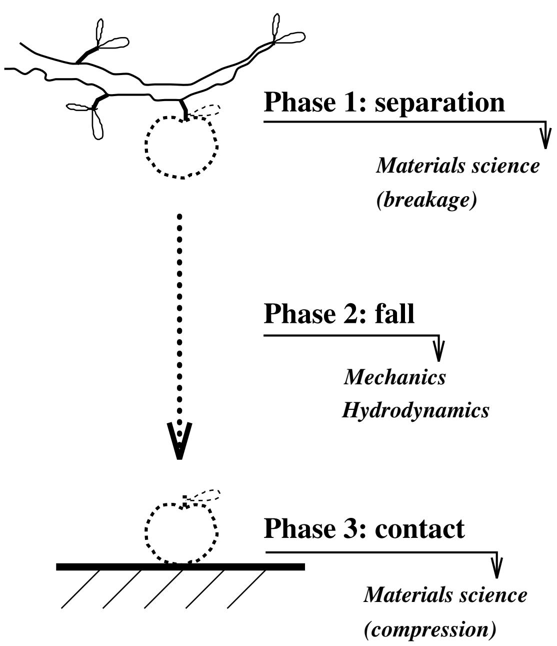

Fig. 1.1. Fall of an apple
Notes: There are (at least) three phases in the fall of an apple, each of which pertains to a different branch of physics. Historically, it was the investigation of phase 2 which proved of paramount importance by leading Newton to his ground-breaking theory of gravitation. 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.

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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

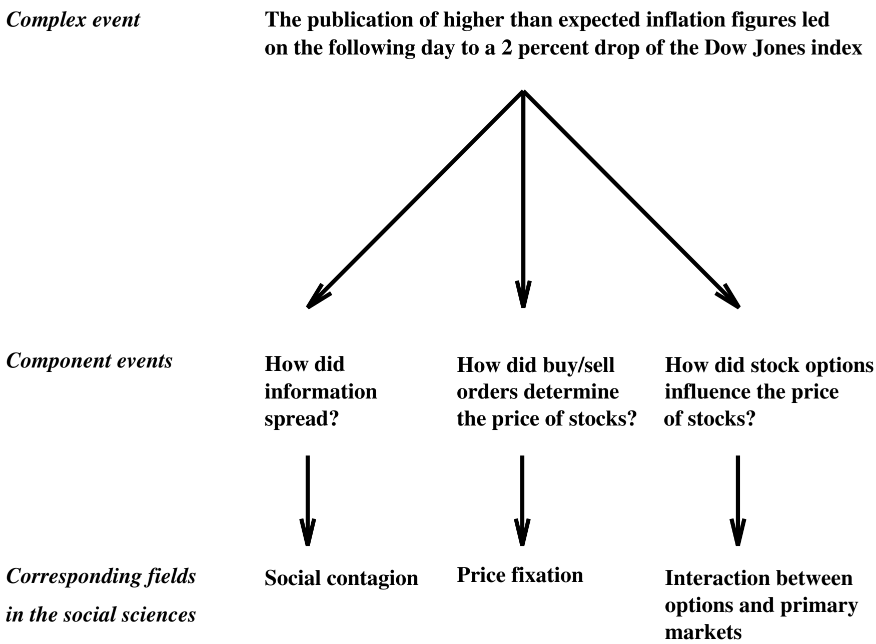

Fig. 1.2. Fall of the Dow Jones index
Notes: At least three different phenomena can be distinguished in the events that brought about a fall in the Dow Jones index. But in contrast to the fall of an apple the specific branches of economics that would treat these different phenomena are not well developed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