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Part I

Basics

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1

Economics and Econophysics

What is econophysics? If it is just the use of physical methods to investigate economic problems, In what way is econophysics different, if at all, from orthodox mainstream economics? If it is really different from mainstream neoclassical economic thought, Is econophysics just another nonmainstream, or heterodox, approach to economic problems? Can econophysics contribute to the understanding of economic phenomena in a different way than economics itself, no matter if this understanding comes from the orthodox or heterodox traditions? Answering these questions form the subject of the present chapter. The next sections will present a discussion on the similarities and differences between economics and econophysics from the methodological and practical viewpoints. For the benefit of readers not entirely familiar with physical terminology, there will be first a very short summary about the origins of modern physics followed by a similarly short overview on the history of economic thought.

1.1 Physics

Physics as a modern science started with the scientific revolution which occurred during the European cultural movement known as the Renaissance. The works of well-known names of that time, like Nicolaus Copernicus (1473–1543), Galileo Galilei (1564–1642), and Johannes Kepler (1571–1630) were fundamental in establishing physics as we know it today. Their contributions spanned the proposal of the heliocentric planetary motion, due to Copernicus, the discovery of the three laws of the planetary motion, due to Kepler, and the law of the falling bodies, due to Galileo, who also made some important contributions to astronomy like the discovery of the sunspots, the biggest four natural satellites of the planet Jupiter, the ring system in the planet Saturn, and the lunar mountain system. Afterwards, the most important advancements in physics are associated with Isaac Newton (1642–1727), whose three laws of motion and his law of universal gravitation

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established what is now known as *Newtonian physics*, *Newtonian mechanics*, or *classical mechanics*. *Thermodynamics*, which macroscopically deals with problems related to heat and temperature, and *electromagnetism*, which studies electric charges, both static and in movement, and magnetic phenomena, as well as the propagation of perturbations in the electric and magnetic fields, the electromagnetic waves, are physical theories whose developments occurred mainly during the eighteenth and nineteenth centuries. The main physicists associated with these theories are Sadi Carnot (1796–1832), James Watt (1736–1819), Michael Faraday (1791–1867), and James Clerk Maxwell (1831–1879). These three major theories, classical mechanics, thermodynamics, and electromagnetism are collectively known as *classical physics*.

During the period lasting from approximately 1870 to 1930, physics underwent a scientific revolution. Starting from results already developed by Maxwell himself, Josiah Willard Gibbs (1839–1903) and Ludwig Boltzmann (1844–1906) used statistical reasoning to describe thermodynamics as a consequence of statistical properties of large ensembles of particles, that is, at a microscopic level, creating then new theories known as *statistical mechanics* and *statistical thermodynamics*. At the same time, contradictions between classical mechanics and Maxwell's electromagnetic theory led Albert Einstein (1879–1955) to propose in 1905 a solution which became known as the *special theory of relativity*. The famous $E = mc^2$ equation comes from this theory. Concurrently, the inability of Maxwell's theory to describe some aspects of the electromagnetic radiation, the blackbody radiation, and the behavior of the fabric of the physical world, the atoms, led Max Planck (1858–1947), Niels Bohr (1885–1962), Erwin Schrödinger (1887–1961), and Einstein himself to establish the basis of a new theory to describe the micro world, the *quantum mechanics*. The use of statistical reasoning was also applied to quantum mechanics and the collection of statistical methods to describe physical systems, classical or quantum, is now known as *statistical physics*.

By the end of 1915, Einstein presented a new theory of gravitation which he had been working on during the previous ten years that went much beyond Newton's one and entirely revolutionized the way physics described the gravitational phenomenon. This theory became known as the *general theory of relativity*, whose conclusions included the very unexpected result, verified empirically, that light beams are deflected by the mass of celestial bodies. The physical theories which appeared from late nineteenth to early twentieth centuries, that is, statistical physics, both relativity theories and quantum mechanics, are now known as *modern physics*.

The paragraphs above are just an extreme summary of approximately the last 450 years of the history of physics and cannot do justice to dozens of other physicists whose names were omitted in the text above, but made very important

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contributions to physics. Several of them were in fact honored with their names becoming physical units used in our everyday life, this being the case for André-Marie Ampère (1775–1836), Andres Celsius (1701–1744), Heinrich Rudolf Hertz (1857–1894), James Prescott Joule (1818–1889), William Thomson, Lord Kelvin (1824–1907), Georg Simon Ohm (1789–1854), Blaise Pascal (1623–1662), and Alessandro Volta (1745–1827), to name just a few. Others like, for instance, Louis de Broglie (1892–1987) and Paul Dirac (1902–1984) made groundbreaking theoretical contributions to quantum theory and both were recipients of the Nobel Prize in Physics.

Nevertheless, our purposes here are not to present a brief history of physics, but to establish the terminology of physical theories to nonphysicists, show the time frame when they were advanced, associate these theories with a handful of names more or less well known to nonphysicists and to state that although at about 120 years ago physics went through a scientific revolution, the previous classical theories were not abandoned. There was no methodological rupture in physics or any kind of dismissal of previous results simply because classical physics agrees with empirical results which are strongly anchored in well-tested experiments. In fact, several technologies used in our everyday life, from electric power to airplanes, are based on the results of classical physics.

What modern physics established were the limitations of classical physics and worked out, both theoretically and experimentally, the new theories to describe physical phenomena placed beyond the scope of classical physics, like the physical laws of the micro world, how bodies behave at speeds approaching the speed of light, and the dynamic connection between space and time. There were naturally new concepts which contradicted classical physics, but physicists worked out the domains of validity of classical and modern physics, including the ranges where those concepts are applicable or not, and nowadays physics works well with both sets of theories in an integrated way.

It must be noted, however, that during these last 450 years several theories and models were effectively abandoned because either their predictions were not validated by experiments or new concepts which described these empirical results rendered those previous theories obsolete. This is, for instance, the case of the caloric theory to explain heat transfer, replaced by the mechanical theory of heat, and the geocentric Ptolemaic epicycles, replaced by Copernicus’ heliocentric system to describe the orbits of the planets, to name just two of several superseded physical theories.

At this point it is important to mention the influence of classical Greek philosophers in the development of physics. Several of them discussed topics which are now considered within the scope of physics, like Democritus (460–370 BC), who advanced the ancient theory of atoms, and, especially, Aristotle (384–322 BC), who discussed the movement of bodies. For the purposes of this discussion one should present one result of the *Aristotelian physics* as examined by Galileo in his famous book titled *Dialogues Concerning Two New Sciences* (Galilei, 1638).

Aristotle claimed that a heavier body would fall faster than a lighter one under the influence of gravity. Galileo refuted this assertion simply because he made the experiment and found that two bodies of the same shape, but different weights, would fall at the same acceleration and reach the ground at the same time if they are released from the same height, a result contrary to Aristotle's conclusion. In other words, in this instance Aristotle's reasoning was deductive and logical, but empirically false. Galileo even questioned if Aristotle ever made the experiment himself (Galilei, 1638, pp. 62–64).

Here we arrive at the methodological essence of the Galilean approach to physical phenomena. No matter how logical and convincing a reasoning can be, it can only be considered scientific if it is subjected to empirical validation, either experimentally or observationally. Until that happens, it is just conjecture waiting to be tested, proved, or disproved. This concept is at the heart of the *scientific method* inaugurated by Galileo, implying that science is an activity whose theories must be constantly checked against observation and/or experimentation and modified accordingly.

After Galileo, the term *Aristotelian physics* became synonymous with *pseudoscience,* that is, presupposed statements assumed as true, but which were never subjected to empirical testing and validation. Hence, *metaphysics*, another word originated from Aristotle's works, is a type of inquiry having nonempirical character, i.e., statements assumed as valid which lead logically to other statements which are also assumed as valid, but never subject to empirical testing and whose final conclusions cannot be considered as having any relationship whatsoever with the real world. That can only happen if they are empirically tested.

Actually, to label Aristotelian physics as pseudoscience is historically unfair to Aristotle, since this only focuses on what was changed in our physical view of the world by the Renaissance's scientific revolution rather than what was *not* changed by this same revolution. Several physical concepts advanced by Aristotle remained after Galileo and became essential building blocks to very important modern concepts in physics. For instance, this is the case of motion as a process, from potential to actual, from where the modern concepts of potential energy (Aristotle, 2012b, pp. 652–655) and dynamics originated. What did not remain were his models, like the geocentric view of the World and the concept of *natural place*, to which objects would seek when moving (Aristotle, 2012a, pp. 913, 1074). Nevertheless, one can even find similarities between definitions and results arising in modern physical theories and the Aristotelian concept of natural place (e.g., Neves, 2018), showing that some fragments of Aristotle's physical models are still with us.

In addition, at Aristotle's time the possibilities of doing experimental physics by means of arithmetic operations with physical measurements were rather limited. One of the main obstacles was the very cumbersome and arithmetically impractical numeral system adopted by the ancient Greeks, where arithmetic operations and the representation of very large numbers varied from hard to nearly impossible, this being specially due to the fact that their numerals did not include the number zero (Ifrah, 2000, ch 16, pp. 327, 333). Galileo, on the other hand, was already in possession of the arithmetically very practical modern Indo-Arabic numerals, where the essential concept of the number zero was already well established, allowed unlimited representation of very large numbers and made their arithmetic operations practical. Nevertheless, although historically unfair, the use of the term 'Aristotelian physics' to mean pseudoscience has remained to this day within the physics tradition.

1.2 Economics

1.2.1 Antiquity and the Middle Ages

Aspects of what constitutes economics as we know it today can be traced back to texts from antiquity which dealt with the justice in the exchange of goods and acquisition of wealth by means of unfair gain in commerce. During this time and the Middle Ages the economic discussion was dominated by Aristotle's ideas about the moral limits of commercial activity, since this was considered as an unnatural way of acquiring wealth. In addition, Aristotle discussed the role of money as a means of exchange, measure of value, and as a stock of value for future transactions (Backhouse, 2002, chs. 1–2).

Scholastic philosophy of the thirteenth century derived from Aristotle's theory of "just wage," which was defined as the wage that would give the worker a standard of living adequate to his social condition. Similarly, there were a just price theory connected to the cost of production through the exchange of equivalents. Included in the cost of production is a fair and moderate profit, enough for the merchant's family and charity (Screpanti and Zamagni, 1993, section 1.1.1).

The sixteenth century saw *mercantilism* dominate economic thought. Its main concerns were no longer the administration of the household, but of the state, no longer the enrichment of the individuals, but of the nation and the merchant class. The goal was the use of state power to build industries and increase the trade surplus by means of exports, leading then to the accumulation of money. The interests of the merchant class were identified with the interests of the collectivity, a situation which meant that economics was no longer domestic, but political (Screpanti and Zamagni, 1993; Backhouse, 2002).

It must be mentioned that many mercantilists were in fact more interested in promoting higher-productivity economic activities through policy interventions; that is, they were focused on solving real-world problems, especially policy proposals on how economically backward countries should develop their economies in order to catch up with the more advanced ones. This focus started a viewpoint in economics that is today known as the *developmentalist tradition* or *development economics*. Developmentalist theories are still being advanced and refined today, although policy practices under this tradition can be traced as far back as the fifteenth century (Chang, 2014, pp. 96–99).

1.2.2 Political Economy

The seventeenth century witnessed the birth of *political economy*, the name by which the study of economic matters became known until the end of the nineteenth century (see Section 1.2.4) and which shows the close connection between economics, politics, social sciences, and philosophy.

William Petty (1623–1687) produced the first texts generally accepted as belonging to political economy, and his book *Political Arithmetick*, written between 1671 and 1676, but published after his death (Petty, 1690), reflected his aspiration at providing an empirical base for economics in which pure speculative reasoning must be avoided, and qualitative arguments ought to be replaced by rigorous ones relying on number, weight, and measure (Screpanti and Zamagni, 1993, p. 36). This was a very good start because if we see Petty's work from the perspective of the early twenty-first century, the time of writing, what he had in mind was really a kind of Newtonian physics of society (Ball, 2004, pp. 3–4).

The next important contribution for the development of political economy came from the French school of thought known as the *physiocrats*. Prominent among the members of the physiocratic school was François Quesnay (1694–1774), whose main contribution was the *Tableau Économique* (Economic Table), published in 1758. The *Tableau* is basically a model that sees the economic system as a cycle of deep interdependence and interrelationship among the various productive processes, that is, all parts of the system function according to a certain natural law. Economic exchange is then represented as a circular flow of goods and money among all economic sectors. Related to this interdependence is the idea of equilibrium, which we would today call *macroeconomic equilibrium* (Screpanti and Zamagni, 1993, section 2.1.2).

According to the *Tableau*, the system is moved by the surplus produced by farmers, considered as the productive class. The landlords formed the distributive class, consuming the surplus created by the productive class and starting the circulation of money and goods among the economic sectors of the nonproductive

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class (manufacturing industry). The circulation is closed by returning part of the surplus to the productive class. Hence, one can find in the *Tableau* three important economic concepts: production, distribution, and accumulation. The accumulation occurs when the production increases by higher quantities of surpluses which are then returned (invested) into production (Delfaud, 1986).

Classical political economy, or the *classical school of economics*, is a term associated with a group of five very influential economists of the eighteenth and nineteenth centuries: Adam Smith (1723–1790), Jean-Baptiste Say (1767–1832), Thomas Malthus (1766–1834), David Ricardo (1772–1823) and John Stuart Mill (1806–1873). Their studies inherited the physiocratic method of viewing the economic system as circulatory in nature, treating this system as a whole and seeing it as being dynamically characterized by three main phases: production, distribution and accumulation (Delfaud, 1986). They, nevertheless, studied in much more detail these three phases of the cycle.

Smith saw the system as a cumulative mechanism operated in a sequence leading to a virtuous circle of growth: division of labor, enlargement of the markets, and increase in labor productivity. The division of labor triggers the growth process and the accumulation drives it. He discussed a theory of *income distribution* among the three basic social classes, capitalists, workers, and landlords, differentiated by the productive resources they hold, respectively, capital, labor, and land, and the way they spend their income, respectively, profits, wages, and rents.

Smith also provided an explanation for the values of goods, which are measured by the quantity of human labor they are able to command, that is, the wage equivalent or the labor that can be bought with it. For Smith, positive growth rate occurs when labor commanded is higher than the amount of labor used to produce it, leading then to a surplus required to sustain capital accumulation. He also distinguished market price, the real price of a good at a certain moment, from natural price, the normal rates of remuneration for capitalists, workers, and landowners. Smith thought of this system as stable, unique, and in equilibrium, since there would be an *invisible hand* where individuals would serve the collective interest exactly because they would be guided by self-interest. However, these three properties of the economic system, stability, uniqueness, and equilibrium, which would justify Smith's conjecture of an invisible hand, remained unproved, and are a source of much debate to this day (Screpanti and Zamagni, 1993, section 2.2).

The other classical political economists discussed the economic system by also using its three phases, production, distribution, and accumulation, as the basis of their analysis. Regarding production, Ricardo discussed Smith's theory of value by arguing that the exchange value must incorporate not only labor, but the tools used in their production, whereas Say argued that the use value implies a certain *utility* that satisfies needs and wants. Mill viewed labor as determining the supply while utility governs the demand. On distribution, Malthus and Ricardo talked about a ‘natural salary’ due to the costs of production of labor, since labor is seen as a commodity as any other. But Malthus stated that if the birth rate increases, the natural salary is reduced to the bare minimum subsistence level. For all classical political economists, profit is at the center of the capitalist dynamics as it provides the accumulation.

Therefore, from Smith to Mill the engine of the economic system is the cycle accumulation–profit–accumulation. Say tried to show that general excess supply is impossible, so arriving at the famous *Say’s law* according to which supply always creates its own demand (Delfaud, 1986; Screpanti and Zamagni, 1993).

1.2.3 Marxian Economics

Karl Marx’s (1818–1883) contributions are well known to be far-reaching, but here we are not interested in the social and political doctrines associated with his name, Marxism, but only in his contributions to political economy, that is, *Marxian economics*, which in fact has a close relationship to the classical political economists, particularly Ricardo’s political economy. His conclusions were based on the labor theory of value, the theory of surplus, and an analysis of the behavior and relationship of social classes, issues already discussed by Smith.

On *(i)* production, Marx viewed capitalism as a *dynamic system* where money (M) and commodities (C) are exchanged in the C–M–C cycle which characterizes a simple commodity production, that is, where commodities produce money which then produces commodities. The M–C–M' cycle is, on the other hand, the dominant form of circulation in capitalism, the part of the system’s dynamics that renders the creation of value as long as $M' >$ M. Thus M' is the final capital whereas M is the invested capital. The difference between M' and M is the *surplus value* or unpaid labor (Delfaud, 1986). Note that Say’s law states that a sale is always followed by a purchase of equal amount, or everything that is produced is consumed. This means no interruption in the C–M–C cycle and, therefore, there is no overproduction, a point which Marx strongly criticized in Ricardo (Sweezy, 1942, pp. 136–138).

On *(ii)* distribution, Marx basically reduced the partition of the produced value in wage share and profits, where the latter is further divided in interests and rent. Finally, on *(iii)* accumulation he noted that capitalist production grows on *cycles of booms and busts*. In a boom, profits increase and unemployment decreases as the workers are capable of obtaining better jobs and higher wages due to manpower shortage to feed the growing production. This boom is, nevertheless, followed by a bust inasmuch as less unemployment reduces the profit margin, whose recovery is achieved by a higher unemployment and a reduction of workers’ bargaining power. Smaller salaries lead to an increase in the profit margin which leads to new