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1 New insights

This book argues that the phenomena discussed within economics can be approached fruitfully, arguably more fruitfully than with traditional ideas and methods, by employing the concepts and methodologies of the natural sciences. In the present chapter we will describe the background to this claim, and some aspects of the contemporary situation in economics.

1.1 A scientific approach

What is the approach of the natural sciences, and why is it so powerful?

Descartes, of course, characterised science as the process of making ourselves free from any prejudice and dogma when seeking truth. Certainly, our capacity for thought is limited or distorted by the influence of religion, politics or, indeed, the received wisdom of established academic disciplines.

However, the fundamental principles of natural science warn us against these traps and require us to face natural phenomena without bias, and to resist the temptation to truncate our inquiries prematurely. Instead, we must ceaselessly root out error and improve our understanding. It was this attitude that enabled Galileo and his predecessors to overturn the prevailing Ptolemaic theory, and to provide a vastly improved model of the truth. Centuries of cumulative endeavour later we have a set of scientific views stretching from the imperceptible world of elementary particles right through to cosmology, the science of the universe as a whole. In between there is chemistry, biology and much else besides. The increasingly technological society we see around us is an outcome of the application of science and scientific method, and of ceaseless improvement in our conceptions of the world. But suppose that mankind had rejected the scientific viewpoint and approach and adhered to less disturbing ideas, to the comfortable traditional thought, for example, of those such as Galileo's contemporary Cremonini,[1] who had refused to make observations through a telescope. Man would still be living in comparative intellectual darkness, with much of

[1] Cesare Cremonini (1550–1631) was a conservative philosopher, and provided Galileo with the model for Simplicio in his *Dialogue Concerning the Two Chief World Systems*.

the potential of our minds, themselves the products of a long evolutionary process, unexploited.

Of course there is more to the history of science and scientific thought than Galileo, but his case is particularly instructive, and further comparison with the present situation in economics is, we think, helpful. Part of Galileo's revolution came about through the use of novel instruments, telescopes, to record previously unrecorded phenomena and aspects of phenomena. Similarly, students of economic behaviour may now use enormously powerful computing resources, and complex software embodying sophisticated mathematics, to collect, observe and analyse large quantities of economic data. It must be emphasised at this point that natural science is more than mathematics, though it is a wonderfully powerful language with which to describe nature. We do not doubt that mathematics will continue to play a hugely important, perhaps growing, role, but mathematics is just a means, not an end. To study natural or economic phenomena in order to exercise our mathematics is fatally to confuse task and tool. Just as it is in the other sciences, our objective in economics is to construct networks of true propositions that model the phenomena under consideration and extend our understanding of the causal processes at work.

Two goddesses are engraved on the reverse side of the Nobel Prize medal for physics and chemistry. Nature is represented by the goddess Natura emerging from clouds and holding a cornucopia in her arm. The veil covering her face is held and being withdrawn by the goddess Scientia, the spirit or genius of science. This allegorical description of the process of science rings true for us. The sciences, the collective intellectual activity of many human generations, are gradually unveiling more and more of the natural world, and of all these research programmes physics is the most rigorous and in some sense the most successful. Bearing in mind the features of economic phenomena, for example their fine-grained and intensely complex character, with micro-causes yielding macro-effects, it is not unreasonable to suppose that the methods of physics may give insight in this field too.

However, individuals are the minimum agents in economic and social phenomena, as consumers and workers, and since our behaviour is controlled by our emotions and thoughts, there is a possibility that we can find no fundamental laws describing these processes. Some may believe that it is impossible in principle to find any law at all. We may recall that Durkheim claimed that social facts can only be explained by other social facts. But science should not, through fear of failure, arbitrarily limit its scope, and in fact physicists have already produced sufficiently valuable findings in economics to justify the expectation of more, and of more general insights. As a consequence there is an emerging and coherent interdisciplinary area, *econophysics*, which, while not being studied in independent academic departments, is the subject of prominent international conferences and workshops.

1.1.1 Science of complex systems

Many readers may have heard of the ‘science of complex systems’ and have some intuitive understanding of its work (Waldrop, 1992; Gell-Mann, 1995; Holland, 1996, 1998). But what does it really mean in practice, and how does it relate to the subject of this book, the study of economic phenomena? Unsurprisingly, the science of complex systems is difficult to explain briefly, but one way to understand it is to take for a moment a different mental perspective from that of the principal philosophy behind natural science, namely the quest for fundamental laws and simpler and simpler explanations.

That is to say we can now see that many complex phenomena in nature are chaotic. Although the behaviour of such a system is derived from a simple law, it is unpredictable. A living thing, for example, should be regarded as a complex object, not simply as an assemblage of parts constituting atoms. That is, we cannot obtain a full picture of such a system by giving a detailed analysis of the individual system constituents. This concept began to gain ground amongst scientists in the 1980s, and is responsible for the emergence of the discipline now known as the science of complex systems.

This point of view is far from incompatible with that of traditional physics and its search for fundamental laws. These are complementary methodologies, a pair of wheels sharing the same axle, and both are necessary if we are to gain understanding of as broad a swathe of the natural world as we can at this time. This is as true for the investigation of economic phenomena as it is for any other aspect of the world. By combining a microscopic study of individuals and companies, one end of the axle, and a macroscopic study of outcomes of complex interactions among individual agents on the other end, we obtain a viable methodology with which we can make progress.

1.1.2 The emergence of econophysics

Only a decade has passed since the term ‘econophysics’ was first used, and it is developing rapidly (Mantegna and Stanley 2000; Aoki 2002; Takayasu, 2002, 2004, 2006; Bouchaud and Potters 2003; Aoki and Yoshikawa 2007; Aoyama *et al*. 2009). The pleasure of being involved in such a challenging and creative phase is extraordinary, but for those meeting the field for the first time it can be disorientating. Some reassurance can be gained from a glance back at the history of the relationship between economics and physics, which is in fact long and close.

For example, no less a figure than Léon Walras established the general equilibrium theory on the basis of the mechanical outlook of the world prevalent in 1860. The theory explains the balance between the demand and supply of goods that determines price by comparing this balance with a mechanical system consisting of a weight suspended from a spring. The forces of demand and supply correspond, respectively, to the gravitational force working on the weight and the restoring force induced in the spring, and the price so determined corresponds to the length of the spring in equilibrium. The agents in this theory thus represent consumers and producers of goods.[2]

However, the effectiveness of such an analogical approach is limited by the lack of both breadth and fine graining in its analytic texture. This matters because actual economic phenomena include such macro matters as the business cycle, and consequently we need to bear in mind the causal significance of the heterogeneity of economic agents, on the one hand, and economic fluctuations on the other. General equilibrium theory, which for instance describes a number of consumers via a single representative agent, is not able to account for dynamic effects in economic activity.

The discipline of statistical mechanics in physics offers understanding of macroscopic states of matter by employing microscopic information relating to atoms and molecules. It is a successful and structurally relevant model for efforts within econophysics to bridge between micro- and macro-economics.

1.2 Distributions and fluctuations

According to statistical data gathered over the last ten years, the Japanese economy is home to about 2.5 million companies.[3] Additionally, Japan has approximately 67 million workers[4] and more than a thousand financial institutions including city banks, local banks, credit associations and governmental organisations. It is possible in principle to:

(a) list all of these economic agents,
(b) gain some grasp of the relationships among them,
(c) observe the financial and employment conditions of these companies,
(d) monitor money flow between companies and banks and between banks themselves,
(e) store the entire data in real time.

This is a daunting task, but we now have well-developed computers equipped with superb CPUs, enormous amounts of memory and virtually unlimited data storage space. But would it be worth the effort? Such a database would certainly give us a perfect description of the whole economy, but it would not make sense for us as outside observers because even a careful reading of the recorded data would tell us nothing about the rise and fall of companies, the main theme of this book. Clearly, some other approach is needed.

Let us move towards an alternative by reminding ourselves how companies are active in the production process. Each company buys materials and services from producers,

[2] In economics, an agent is a constituent in a model used to solve an optimisation problem. Economic agents include, amongst others, households, companies, central banks and governments.

[3] The total number of companies is based on a census taken by the National Tax Administration Agency. Other censuses by the Ministry of Internal Affairs and Communications and the Ministry of Justice give different numbers. Accurate estimation of the number is said to be very difficult. For example, it may be overestimated by an over-thorough count, which includes inactive companies, or underestimated because the research is too cursory.

[4] This number is based on a census by the Ministry of Internal Affairs and Communications. The database covers workers over fifteen years old and also includes persons with no employment at all.

adds value, perhaps by transforming them into other materials, services or products, and sells them on to other consumers, which can, of course, be other companies. In this process of earning money, the company employs its capital and labour along with its own creative ideas. We can see, therefore, that if we can trace the chain of money flows we will have described a very important aspect of the behaviour of companies.

To this end we can conduct statistical manipulations on the microscopic data relating to the 2.5 million Japanese companies and so extract coarse-grained representations. For instance, we might focus on the number of companies falling in the capital ranges of ¥1 million – ¥10 million, and more than ¥10 million. This kind of macroscopic view of the data in terms of statistical distributions will play a primary role in approaching the dynamics of the rise and fall of companies.

This is an idea akin to the approach adopted by statistical mechanics, but we are not claiming that the methods of this field are straightforwardly transferrable to economic phenomena. To gain understanding of any phenomenon, whether it is natural or socio-economic, we must distinguish between the topic's essential and inessential elements. Otherwise, we shall simply list all the data available, an act which yields little or no insight. Furthermore, we may encounter phenomena which do not lend themselves to that style of analysis. In fact, the rise-and-fall dynamics of companies are not random, and, as we shall demonstrate from real data, certain dynamical patterns can be discerned, one of these being the distribution of corporate magnitude. Indeed, it was Pareto, to whom we shall refer repeatedly in this book, who first pointed to this curious truth.

The first step in getting to grips with this matter is to recognise that the distribution of company size is not bell-shaped, but significantly skewed. The normal (or Gaussian) distribution, familiar from general statistics, is a typical example of bell-shaped distributions, and if company sizes were distributed in the normal form, we would find a majority of companies of average size with a few exceptional companies of very small or very large size. But study of the data shows that, in fact, companies are classified into two groups, a small number of giant companies and a large number of small and medium-size enterprises. If we remove the giants and examine the remaining companies we find that they can classified into two groups, the very large and the rest, a procedure that can be carried out repeatedly. This real-world distribution is characterised by a self-similar hierarchical structure, an aspect of the finding with which some readers may already be familiar. However, a non-trivial point is that the distribution obeys a specific form of distribution, the power-law distribution, details of which are discussed in Chapter 2.

Of course, distributions are just collections of snapshots of living companies. If we are hoping to shed light on the dynamics behind these distributions, we need to analyse any fluctuations, such as variations in capitalisation, which reflect the driving forces of production activity. In a static model where everything is balanced without fluctuations, there would be no dynamism at all, and it would be impossible to understand how a particular pattern is brought about and under what conditions the pattern is destroyed. However, where there are fluctuations, and they are invariably present in real-world

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cases, they are very revealing, and in Chapter 3 we will show that such fluctuations have a distinctive pattern giving rise to a specific distribution.

Vilfredo Pareto

Vilfredo Pareto (1848–1923) was an Italian economist. He was born in Paris to an Italian father and a French mother, and raised in that city before returning to Italy to study mathematics, physics and engineering at the University of Turin. Subsequently he worked as a civil engineer for the Italian state railway company and then for an iron works, of which he was for ten years the director. During this time he became a fierce proponent of free trade and minimal government regulation. This led him to intense political activity, and then to a new career in economic studies.

Under the influence of the neo-classical economist Léon Walras, he became a professor in economics in the University of Lausanne at the age of forty-six. His book *Cours d'économie politique* (1896–7) describes the power law that he both proposed and fiercely defended against criticism. Pareto's power law is one of the central components of the econophysical studies of companies and other agents in the real economy, not to mention many other social and natural systems where self-similarity is observed.

As has been remarked, analyses of real data show that there are clearly visible patterns in the distributions and fluctuations relating to companies, and that these are independent of variables such as country and time. The existence of such universality in such phenomena is extremely surprising from the perspective of economics, and encourages the use of the methodologies of natural science in their analysis. But the difficulty of the problem that faces us should not be underestimated, for as we try get to grips with the dynamics of the growth and failure of corporations, we will find that we are seeking an understanding of the interactions between agents, that is, of an economic network formed by the enormously complicated pattern of relationships among agents.

1.3 Are networks complex?

The power-law distribution, which is observed ubiquitously in nature, is a critically important concept in this book, and has in recent years been used to great effect in network science, a relatively new science dealing with a wide variety of phenomena, ranging from the microscopic, for instance in biology where it discusses gene networks, metabolic networks and the interaction network among proteins, right through to the macroscopic, where the Internet provides us with typical examples (Watts, 1999, 2003; Barabási, 2003; Buchanan, 2003; Caldarelli, 2007). For instance, researchers are also interested in communication networks formed by providers and companies, and the linking structure of web pages, social networking services (SNS), the trackback network of blogs, and so on. Other examples might include co-author relations among researchers and friendship networks among football players.

At first glance it may be difficult to believe that the members of such an apparently heterogeneous collection of networks have any common features, but in fact there are several, a fact that points towards the existence of some *universal law* behind the formation processes of networks. On the other hand, it is also true that each network has its own characteristic features, and one of the challenges confronted by network science is to explain how these facts co-exist.

The application of network science theory to economic phenomena is described and argued for in detail in Chapter 4, but for the time being few readers will object to the claim: 'The economy is a very large network consisting of economic agents directly and indirectly linked to each other.' Interestingly, although such a proposition seems unobjectionable, almost commonplace, the idea of studying economic systems from the point of view of networks is a recent one. For instance, the pioneering book written by economists with this perspective was published only in the 1980s (Piore and Sabel, 1984).

Here we pay special attention to the growth and failure of companies interacting with each other over various kinds of business network. Such intercompany networks underlying the dynamics of companies include mutual shareholding relationships, linkage between companies established by interlocking directorates, transaction relationships between sellers and buyers, and collaborative innovation emerging by means of joint applications for patents.

The authors began their study of business networks around 2000, and at that time, even at international conferences, there were very few presentations on this topic. However, since that time the number of papers on this theme has increased rapidly, and network science is now one of the key terms at such gatherings. This dramatic change is a clear indication of the growing understanding that recent developments in network science are relevant to all fields, with economics being no exception.

Indeed, there are points of very close contact between economics and network science, for example the environment surrounding companies is a rapidly changing one, and accordingly the relationship between companies experiences a dynamic influence. Consequently, it is dangerously misleading to focus our attention exclusively on a single company while neglecting its relationships to other companies. Taking a broader view will reveal new aspects to what is actually happening in the industrial economy, a topic that we will take up in the next section.

1.4 Change in the environment surrounding companies

In recent years industry has made a marked shift from *vertical integration* structures to those characterised by the *horizontal division of work*. As a result, managers and analysts have begun to recognise just how important the formation of networks is for corporate competitiveness. Environmental changes of this kind occurred in the electrical and electronics and automobile sectors, two major industries in Japan, from the late 1980s onwards.[5]

1.4.1 Outline of the Japanese electrical and electronics and automobile industries

By the mid 1980s, conglomerates in the electrical and electronics sector, for example Hitachi, Toshiba and Mitsubishi Electric, had established their positions in the Japanese economy. They produced the whole range of electrical and electronics manufactures. For instance, their product range spanned appliances, electronic components, such as liquid crystal panels and DRAM chips, electric power equipment, such as power generators and power grid systems, computers and system integration, such as a bank's mission-critical systems, to telecommunication equipment, such as routers. Their business strength came from their wide product range, because the phase and period of the business cycle of one kind of product are different from those of another kind. They had grown steadily for a long period without experiencing seriously poor performance. It is well known today that a major origin of high profitability in the 1980s was the export of DRAM chips to the USA.

On the other hand, the automobile industry established a unique strength in production systems through continuous effort for decades. The industry consists of several automobile manufacturers, such as Toyota, Nissan and Honda, and a very large number of auto-parts manufacturers, producing transmissions, brakes, electronic engine controllers and other components. Most of the auto-parts manufacturers are located near the factories of automobile manufacturers. They supply various auto-parts immediately to the factory requesting parts. This supply method brought a very high efficiency to their production system. Automobile manufacturers made various small and medium-sized cars in Japan, and exported them mainly to the world's biggest market, that is the USA.

In the middle of the 1980s Japan came under sharp criticism from the USA for its continuously growing trade surplus. A long sequence of repeated negotiations between the two countries eventually created a new economic context for Japanese industry, and after the Plaza Accord was signed by the economically developed nations, the relative value of the yen increased rapidly, with the consequence that automobile manufacturing plants were relocated to the USA. At the same time, various political schemes were devised to increase domestic demand. After the termination of the Cold War, however, political interventions of this kind were rejected, and were ultimately succeeded by an era of deregulation. This sequence of policy changes had consequences for industrial structure, and business networks are key to understanding these changes.

[5] Business environmental changes in the global economy are explained from the viewpoint of the USA in Dertouzos *et al*. (1989) and Berger (2005).

1.4.2 The electrical and electronics industry

In the 1980s Japanese companies survived intense competition from American companies in the manufacture of audio-video equipment such as video recorders and televisions. This was also broadly true for companies making components for personal computers, such as liquid crystal panels and DRAM chips. As a result, the US government accused Japan of dumping DRAM chips, and forced Japan to monitor its export prices by concluding the Japan–USA Semiconductor Agreement (from 1985 to 1995). In the process of increasing the production of liquid crystal panels and DRAM chips, Japanese companies built their plants in Korea and Taiwan, a decision motivated in part by the desire to avoid trade conflict. To reduce possible risks in these projects the Japanese companies asked local companies to invest in the business and in return offered technical expertise. This period of activity overlapped to some degree with that during which the Japan–USA Semiconductor Agreement was effective. The point to emphasise here is that Japanese companies changed their industrial structure from vertical integration to a horizontal division of work by switching from *self-manufactured* components to those *outsourced* through collaboration with companies abroad. It should also be remarked that the distribution of process units also entailed the leakage of production technologies.

Although Japanese companies became front-runners in the 1990s, this golden age did not persist for long, as companies were exposed to aggressive competition from Korean and Taiwanese companies, and a price drop due to overproduction. Furthermore, the Japan–USA Semiconductor Agreement seriously damaged Japanese companies and at present Japan has only one manufacturer of DRAM.

Putting aside the subject of specific components for personal computers, there are other more general problems regarding general environmental or contextual change in the computer manufacturing sector. Until the 1980s the computer world was largely a closed system, in which Japanese companies were able to maintain high-profit business in IBM-compatible mainframe computers for the mission-critical systems of banks and other large financial institutions. This was an age of vertical integration. However, after the end of the Cold War in 1990, a new period of *open systems* emerged, one characterised by personal computers and networks. At that time Japanese companies failed to gain control of the standardisation of the CPU for personal computers, so they had to follow an industry standard determined by companies in the USA. The simple assembly of components and the localisation of software packages were not sufficient to permit Japanese companies to take advantage of cumulative technological development by making further progress, and consequently the superiority of Japanese companies has gradually been eroded.

The explosive development of the Internet led to a coming of age, if not quite maturity, in the late 1990s, and, combined with deregulation policies, has radically transformed the industrial structure of communication equipment businesses from vertical integration to horizontal division of work. The new wave has all but destroyed the industrial cluster consisting of NEC, Fujitsu and Hitachi, once called the ‘Denden family’, and the Nippon Telegraph and Telephone Public Corporation, NTT, which exerted near complete control over this family, which it also supported. Even Japanese companies which manufacture telecommunications equipment for open systems, such as routers, are being out-competed. In contrast the USA has a number of highly profitable fabless companies[6] such as Cisco, which can respond promptly to market needs by simply switching manufacturer. This remarkable outcome is a clear manifestation of the strong causal relationship between network formation and competitive powers.

In addition, the electric power equipment sector is undergoing drastic changes because of deregulation. The electric power industry is typical, having been government-controlled until the 1990s. Companies making electric power equipment were able to maintain high profit margins via their relations with the power companies. However, deregulation of the energy market, which started around 2000, has begun to change this intimate relationship.[7] Some equipment-makers even have their own power plants to sell electricity to power suppliers, and in future it is expected that the formation of business networks among generators and suppliers will lead to reductions in the price of electricity.

1.4.3 The automobile industry

Like the electrical and electronics sector, the automobile industry has also undergone global reorganisation as a consequence of a trade conflict between the USA and Japan; in particular, Japanese companies were prompted to build manufacturing plant in the USA. However, it was the acquisition of Chrysler by Daimler-Benz that triggered the most important phase of global reorganisation. The fact that size matters for survival was widely recognised, as might be guessed by the coining of the term ‘Four Million Club’ to refer, somewhat enviously or complacently, to those automobile manufacturers producing over 4 million vehicles per annum.

However, in examining the industrial structures of Japan, we observe no fundamental change that excludes certain of the automobile manufacturers. Similarly, in the USA we observe an industrial system established with the co-operation of the Japanese automobile manufacturers and auto-parts manufacturers. Indeed, Japanese companies have now caught up with US companies in sales numbers in spite of the fact that these American companies retain a strong influence on the market. This is partly because these US companies must incorporate very large welfare costs, including pension and medical payments for retired employees, into the prices of cars. By comparison, Japanese companies enjoy relatively low costs for welfare, in addition to efficient production technologies, and can therefore increase their market share and maintain a healthy profit margin. Concerns with regard to energy security and environmental pollution have provided a tailwind for those Japanese companies excelling in the

[6] A fabless company is an equipment manufacturer that does not have its own manufacturing capability for electronic components, which is known as a *fab*.
[7] US experience of the deregulation of electric power is instructive, since it allowed the emergence of Enron, the notorious collapse of which due to a large number of improper transactions was one of the defining corporate scandals of our time, and has focused discussions of corporate governance.