CAMBRIDGE
Cambridge University Press & Assessment
978-1-009-54772-7 — Complexity in Economics
Giacomo Gallegati , Mauro Gallegati , Simone Landini
Excerpt
More Information

Introduction

The 2007–2008 crisis was both a crisis of the real economy and a crisis of the dominant economic theory (Kirman, 2010). The question increasingly being asked is whether the 'Great Recession' is prodromal to the emergence of a new paradigm.

The road followed by economics is bumpy: the dominant economic model is fragile and weakly validated, and there is resistance to paradigm shifts. The alternative – very promising and adopted by many disciplines – is far from complete. There is a paradigm difference between standard economic theory and complexity theory. Standard economic theory is based on closed systems with agents that act independently, are homogeneous, and make rational choices, leading to economic results of static equilibrium or steady growth. Complexity theory analyses the economy as an open system, subject to new innovations and information, composed of heterogeneous agents with limited rationality giving rise to networks of interactions and institutions, and an outcome of disequilibrium characterised by continuous change due to innovation and imperfect and incomplete information. In such a case, the system is complex – that is, described by phenomenological laws that are not immediately descended from the laws describing the behaviour of the individual components.

The physics of complex systems has shown that equilibrium cannot be applied in the presence of irreversible phenomena, where the arrow of time matters (Waldrop, 1993; Nicolis and Nicolis, 2007). In the case of economic systems, the second law of thermodynamics is valid (Georgescu-Roegen, 1970) and, moreover, there are learning and interactions because there are informational constraints not contained in the price system. Reductionism and equilibrium are consequences of the closed-system functioning applied to the economy, considered as a structurally stable system, as often presented in standard textbooks: the economic process is reduced to a circular diagram with a peculiar movement between production and consumption (Georgescu-Roegen, 1970).

Innovation and informational limits stimulate agents to interact, and the way of interaction changes because of learning. Interaction takes place through changing networks of heterogeneous agents (Bookstaber and Kirman, 2018). Interaction produces emergent phenomena where the total outcome of a process is no longer the sum of the components (Anderson, 1972). If information is imperfect, because it is not homogenously distributed, there is room for interaction between agents with heterogeneous information sets. Accordingly, the mathematical framework to adequately model interaction is based on non-linearity, far beyond homogenous distributions and predictable proportional reactions to change.

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE

Cambridge University Press & Assessment
978-1-009-54772-7 — Complexity in Economics
Giacomo Gallegati , Mauro Gallegati , Simone Landini
Excerpt
More Information

The literature has claimed that the main elements causing structural dynamics are technological innovation (Griliches, 1979; Fraenken, 2006; Foster and Metcalfe, 2009; Antonelli, 2011; Bloch and Metcalfe, 2011) and knowledge (Fischer and Fröhlich, 2001). Complexity consists in the endogenous change of preferences and technologies made possible by the interaction of agents that act purposefully in a context shaped by non-ergodic processes (Antonelli and Ferraris, 2017). The key contribution of Schumpeter (1947), with the notion of ‘creative destruction’, as well as the contributions of the new growth theory (Romer, 1994), make an important step forward, although this assumes that the effect of knowledge spillover in terms of dynamic increasing returns is automatic. The contribution of Paul David (2000), regarding the distinction between ergodic and non-ergodic processes, points out that if the introduced innovation has success, it changes the ecology and the interactions, and creates new boundary conditions and a new information set. Consequently, it is no longer possible to use differential or difference equations in favour of the complexity and the computational approach (Thurner et al., 2018).

These arguments determine the existence of a structurally unstable system, analysed as a complex system (Arrow, 1994; Arthur et al., 1997; Arthur, 1999; Beinhocker, 2006). Complex systems are populated by many heterogeneous interacting agents. Moreover, structural instability entangles with path dependency, non-ergodicity, and learning. Time is historical, as it chronologically orders irreversible events, and the disequilibrium generated by that change – that is, the *primum movens* of capitalism – also drives the main analytical approach.

The non-equilibrium emphasises structural breaks: subsequent interruptions that come from agents that adapt to a situation that continuously changes. Complexity emphasises agents that react to changes made by other agents. Therefore, there can be aggregated equilibrium and individual disequilibrium. Taking this aspect into consideration certainly complicates the concept of equilibrium, because it introduces a variability that the general equilibrium model shuns and leads to the impossibility of rational expectations. Statistical physics has been used to overcome the limitations of a deterministic description in favour of a probabilistic one, whose states are not a priori but may change via interaction of heterogeneous objects.

The economy is a complex system, wherein the macroscopic outcome is not the mere sum of the micro-ones and the tools of the statistical physics become essential. The ordinary tools of the standard economist remain valid only for the very short period when the system can reasonably be assumed to be closed and its structure does not change. Moreover, human agents are, unlike atoms, thinking entities with free will. Agent modelling (Gallegati et al., 2024) thus seems the most suitable tool to analyse the behaviour of individuals, their interactions, and the emergence of empirical facts not found in individual properties.

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE

Cambridge University Press & Assessment
978-1-009-54772-7 — Complexity in Economics
Giacomo Gallegati , Mauro Gallegati , Simone Landini
Excerpt
More Information

Economics was born as political economy, to manage the change in society due to the advent of the industrial revolution. This happened before economics had the ambition to resemble physics and become a science (Mirowsky, 1989). One of the purposes of that classical political economy is to be useful to society to facilitate the process of growth and obviate the pathologies that it entails. If this purpose still has meaning, economics must equip itself with tools to look for the keys where they have been lost and not under a streetlight just because there is light there (Fitoussi, 2013).

As it has been understood in the hard sciences, complexity theory puts an end to the time of certainty, to the correspondence between cause and effect and predictability. As we will see, the dominant economic theory is based on the equilibrium and separability of systems, categories that are appropriated only for some systems of classical physics, which an economist would define as macroscopic. To study microscopic behaviour, statistical physics has introduced the probabilistic interpretation. There is then a contrast between a deterministic interpretation, which considers the equilibrium of each individual agent and therefore of the system, and a stochastic interpretation. According to this view, individual behaviour is random but leads to an equilibrium of statistical type, in which individual elements can be in disequilibrium while the system reaches a ‘state of compatibility’. In the transition from micro- to macro-description, new facts emerge, which are not present at a lower hierarchy, for which the ‘laws’ are valid only at their specific level of disaggregation. For these reasons, the whole is different from the sum of its parts (Anderson, 1972), the properties of the whole derive from the interaction between the parts, and this implies non-linearity and uncertainty. This suggests the abandonment of the dream of being able to formulate a ‘natural law’, of the predictable proportionality between cause and effect and of the dynamics of a system that can be reconstructed as the sum of the effects of individual causes acting on individual components (Nicolis and Prigogine, 1977): it is a requiem for methodological individualism.

To link the micro-economy with the macro-economy, the *mainstream* approach introduced the framework of the ‘representative agent’ – an average isolated agent, who acts regardless of the behaviour of others – which is as analytically useful as it is fallacious and a harbinger of error. In this way, an attempt has been made to reduce the macro-aggregate to the micro-part by construction, which gives the idea of a possible, but false, micro-foundation – to say nothing of the impossibility of the analysis of income distribution, wealth, and agent size or, more generally, composition effects (Kirman, 1992). Nevertheless, though devoid of any ontology, the analogy is so convenient and effective that it is still used more than a century after its introduction.

© in this web service Cambridge University Press & Assessment www.cambridge.org

Cambridge University Press & Assessment
978-1-009-54772-7 — Complexity in Economics
Giacomo Gallegati , Mauro Gallegati , Simone Landini
Excerpt
More Information

The maximum–minimum (utility and cost) method derives from the analogy with classical systems of physics, deterministic and separable, and the principles that must be introduced are necessary (ad hoc) axioms to reduce the behaviour of economic agents to that of atoms. This happened around 1880 with the marginalist revolution of Jevons, Menger, and Walras, which aspired to transform the discipline of economics into a quantitative social science.

Almost at the same time, Boltzman's work was published and, shortly before, the second law of thermodynamics was formulated. On this basis, it was discovered that entropy always increases in closed systems, that matter and energy are neither created nor destroyed, but that every active process absorbs valuable resources (low entropy) and releases unhelpful waste (high entropy), and that this process is irreversible. The economic process cannot escape this physical law; in fact, even for economic processes the arrow of time matters – they are not circular but unidirectional – and irreversibly leads them from states of low entropy to successive states of higher entropy. Outside Newtonian determinism, where there is time symmetry, time matters. The neoclassical theory could not register the novelties of physics and limits itself to extending, axiomatically, the macro-perspective to the micro one, following a procedure disavowed by statistical physics.

The use of mathematics gave economics an authority that became a presumed objectivity and hid the identification of ideological reflections that precede the analytical phase in the social sciences (Schumpeter, 1954): the analytical construction of any economic theory is preceded by the ideological vision. This approach to economics is a decisive factor in the definitive affirmation of economic thought in the terms of the formal language of mathematics. For the first time, the axiomatic-deductive method is applied outside of the traditional contexts in which it had been developed (e.g., logic, arithmetic, geometry) and from which the natural sciences were able to take advantage successfully. Physics employs results that mathematics has axiomatically deduced in a rigorous way to formulate explanatory theories of the laws of nature and adopts them only after their empirical validation. A similar procedure is less common in economics, because of both the paucity of experimental data and the non-replicability of many events. For example, the real business cycle is the case of an economic theory incapable of explaining the facts but for more than a decade it was successful, even though the empirical evidence was in blatant contrast to the assumptions of the theory itself. There is no doubt that the behaviour of human beings is more difficult to describe through mathematical models than the behaviour of atoms. It is not sufficient to adopt the forms and methods of physics to model economics based on some analogy because agents are not atoms and economics is a social discipline that cannot disregard the importance of history.

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-009-54772-7 — Complexity in Economics
Giacomo Gallegati , Mauro Gallegati , Simone Landini
Excerpt
More Information

Ultimately, there is an information problem: only in a closed, barter system – with complete markets and perfect information – do prices act as coordinators. However, when prices do not only reveal excess supply or demand, the market is no longer efficient (Grossman and Stiglitz, 1980). As we shall see, the general economic equilibrium model in the Arrow–Debreu formulation is not robust to minimal informational constraints. Both its 'optimal' theorems and economic policy suggestions are merely *logically consistent* mathematical exercises of an incorrect and *incomplete* system. Arrow and Debreu's model is mathematically unassailable if it is decoupled from the phenomenon to be described: an economy in search of equilibrium. The general equilibrium as an economic fact is transformed into a mathematical fact because of a set of axioms necessary to find the solution with a logically consistent procedure from the syntactic point of view, regardless of its correctness from the semantic point of view. This model is incorrect if we consider it as an economic model because it fails to describe any real economic system, although this was the original intention of the general economic equilibrium theorists. In formal terms, Arrow and Debreu's model is an admirable work that shows which and how many restrictions are necessary to find a solution to the problem of proving the existence of equilibrium. More than a descriptive model of the economy, it is an argument that shows the limits of thinking about economics through its abstract mathematisation, deprived of its phenomenology, without ontology but only by weak analogy. This is also true of the current dominant modelling: the dynamics stochastic general equilibrium (DSGE) models.

Economics is a social and evolutionary discipline. It deals with non-equilibrium complex systems, where the agents are numerous, heterogeneous, interacting, strategically thinking, and capable of learning. Their coordination comes from below, from the action of individual agents through the phenomenon of self-organisation. The dominant approach in economics adopts equilibrium as an ideal tool, implicitly assuming that economic systems are 'natural systems', whose empirical regularities do not change over time, so much so that we talk about 'natural laws'.

Table 1, from Axtell et al. (2016), highlights the main difference between the mainstream and the complexity approach to economics.

Non-equilibrium physics has shown that new tools are needed to analyse evolution. In this perspective, agent-ased modelling (ABM) is the methodology that seems most appropriate for studying a complex economic system (Gallegati et al., 2024). And so, just as equilibrium is a special case of non-equilibrium and linearity of non-linearity, we will see that the *mainstream* is a subset of complexity economics. This Element highlights that, since the economic system is complex, it can only be studied through a methodology appropriate to

© in this web service Cambridge University Press & Assessment www.cambridge.org

Cambridge University Press & Assessment
978-1-009-54772-7 — Complexity in Economics
Giacomo Gallegati , Mauro Gallegati , Simone Landini
Excerpt
More Information

Table 1 Contrasting perspectives on economic theory and models

Economic conception	**Conventional representation**	**Complex, evolutionary approach**
Number of agents	Representative (one, few)	Many (possibly full-scale)
Diversity of agents	Homogenous or few types	Heterogenous, possibly all unique
Agent goal, objectives	Scalar-valued utility, fixed	Other-regarding, evolving
Agent behavior	Rational, maximizing, brittle	Purpositive, adaptive, behavioral
Learning	Individual, social	Empirically grounded, group
Information	Centralized, free, uncertain	Distributed, costly, tacit
Beliefs	Coordinated for free	Uncoordinated, costly to coordinate
Interaction topology	Equal probability, well-mixed	Social networks
Markets	Walrasian, single price vector	Decentralized, local prices
Firms and institutions	Absent or unitary actors	Multi-agent groups
Selection operators	Single level	Multilevel
Governance	Median voter	Self-governance, rule evolution
Temporal structure	Static or equilibrium dynamics	Disequilibrium dynamics
Source of dynamism	Exogenus, outside economy	Endogenous to the economy
Properties of dynamics	Smooth, differentiable	Irregular, volatile
Character of dynamics	Markovian, path is forgotten	Path-dependent, history matters
Solution concepts	Equilibrium at the agent level	Macro steady-states (stationarity)
Multilevel character	Neglected, fallacy of division	Intrinsic, macro-level emerges
Methodology	Deductive, mathematical	Abductive, computational
Ontology	Representative agent	Ecology of interacting agents
Data	Simple, aggregate	Micro-data, Big Data
Policy stance	Designed from the top down	Evolved from the bottom up

From Axtell et al. (2016).

© in this web service Cambridge University Press & Assessment

CAMBRIDGE

Cambridge University Press & Assessment
978-1-009-54772-7 — Complexity in Economics
Giacomo Gallegati , Mauro Gallegati , Simone Landini
Excerpt
More Information

replicate (*in silico*) certain events that are unrepeatable in fact but can be simulated by constructing agent systems and studying their networks of connections (Gallegati et al., 2024).

In this Element, when we refer to 'economic theory' we refer to the dominant, or *mainstream*, economic theory. Moreover, by 'classical physics' we mean the physics that deals with non-relativistic and non-quantum phenomena. In the sections there are some boxes that deal with specific topics by fixing the main notions – those that can be recalled at various points in the text to facilitate the reading.

This Element is divided in two sections: *1 How Economics Came to Believe It Was a Natural Science; 2 Economic Complex Systems*. In Section 1 we deal with closed, non-complex systems characterised by equilibrium analysis. These are the economic general equilibrium systems inspired by classical physics from Walras to Arrow–Debreu to DSGEs (Section 1.1). In Section 1.2 we highlight the limitations of this general equilibrium model through some theorems formulated by the same economists who contributed to its formulation (Arrow, Debreu, Hahn), both by critics of its development as DSGE (Solow, Stiglitz) or by mathematics itself. In Section 1.3 we are interested in open systems and their inclusion in complexity economics. Economic system analysis can be split between closed and open systems, emphasising that only the former can properly use the tools of equilibrium while those of complexity must be applied to the others. Moreover, since economic agents are 'social atoms' (Buchanan, 2007) the theory becomes non-ergodic, from ergodic as it was in physics.

Section 2 is devoted to complexity. We first introduce some of the founding notions, such as statistical equilibrium and non-separable systems. Section 2.2 is based on self-organisation, scale invariance, and self-organised criticality. Section 2.3 aims at framing complexity economics, with attention to the notion of emergence.

This Element is accompanied by *Agent-Based Modelling: A Tool for Complexity* (Gallegati et al., 2024), also in this series.

1 How Economics Came to Believe It Was a Natural Science

> *Let economics not be afraid to become an axiomatic-deductive system,*
> *assuming idealised economic agents and processes,*
> *just as physics makes great use of entities such as rigid bodies,*
> *inextensible and massless wires, perfect gases, frictionless surfaces,*
>
> Vilfredo Pareto (in Bischi, 2012, p. 10; our translation)

The year 1816 was a year without a summer because a meteorological anomaly, with the complicity of the eruption of the Tambora volcano in

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-009-54772-7 — Complexity in Economics
Giacomo Gallegati , Mauro Gallegati , Simone Landini
Excerpt
More Information

Indonesia in the previous year, resulted in a sharp drop in temperatures (Schurer et al., 2019).[1] During that exceptionally rainy summer, Lord Byron's guests were forced to stay indoors for long periods of time, entertaining themselves with scientific-philosophical discussions and readings of stories about ghosts and other topics that always tickled the imagination. Among them was Mary Shelly, who wrote *Frankenstein*, a novel marked by many arts and philosophies of the past. Baron Victor von Frankenstein's scientific genius is caught up in the illusion that he can dominate creation, until he discovers that the 'monster' is, for him and the community, more a cause of repentance and terror than success. The same is true of *mainstream* economics. Theoretical conceptions and models have gotten as out of hand for economists as the creature got out of hand for the baron. In these models we find various characters, from various stories as realistic as they are unreal, 'as if' they had been written at Villa Diodati in 1816: the invisible hand, the occult auctioneer, the benevolent dictator, Laplace's demon, and the representative agent.

1.1 A Brief History of the Mainstream

It should first be noted that the 'pre-analytical' visions between *mainstream* and complexity economics are so distant as to be irreconcilable. The former deals with timeless closed systems, complete information, and non-interacting agents, modelled as if they were real barter economies. The latter deals with open systems and monetary economies, where information is limited and agents interact. The first aims to explain the exchange, the second is concerned with the genesis of profit.

The distinction between cooperative barter economics and monetary economics is due to Keynes, and he takes it from Marx. The barter economy is that of the allocation of given resources, of the exchange between, for example, a producer of apples who would also like to eat peaches and who, for this reason, seeks another who exchanges peaches for apples. If the producer wants milk, he must look for a milkman who wants apples. And so on for every good you wish to exchange. Money thus avoids recourse to barter. The same happens with banks that intermediate supply and demand for savings. Everything takes place in monetary terms for the same reasons mentioned here, and money is only a commodity that acts as a facilitator of trade.

In capitalism, what counts is credit (debt), not money, because it links today's investment to tomorrow's profit rate, thus opening the doors to dynamics. Similarly, banks are limited to intermediate between those who save and those who invest, transferring something already existing from one subject to another.

[1] 'Eighteen-sixteen was the year without a summer' (Rasputina; On Perilious World; Filthy Bonnet Co., 2007).

© in this web service Cambridge University Press & Assessment www.cambridge.org

CAMBRIDGE
Cambridge University Press & Assessment
978-1-009-54772-7 — Complexity in Economics
Giacomo Gallegati , Mauro Gallegati , Simone Landini
Excerpt
More Information

Production has already taken place and money – and banks – serve only to facilitate exchanges. Whether or not there are banks and currency, the result does not change: they are inessential to the general economic equilibrium models, both in Arrow–Debreu and in DSGE models. If barter is perfect, then there is no need for money. If there are frictions, then money is needed, but this assumes that there can be exchanges outside the equilibrium, which implies multiple equilibria all with different Pareto efficiencies, and which therefore come to be improvable – see the Greenwald and Stiglitz theorem (discussed later in the Element).

In a monetary economy, more money must be obtained from money, whereby the aim of production is not the satisfaction of consumers' needs but the realisation of a monetary profit. If one produces for profit, one no longer has the exchange of one commodity for another, but the transformation of money into commodity and again into money. Time enters the scene and money becomes capital. In the monetary cycle, money is used to obtain more money in the form of a monetary profit.

Banks produce credit. Compared to the barter-*mainstream* view, where banks are intermediaries of a commodity already produced between those who save and those who invest in a context that remains one of exchange, in a monetary economy money becomes endogenous – that is, loans create deposits (i.e., one lends what has not yet been produced).

The analytical inconsistency of the *mainstream* is illustrated by the so-called neoclassical aggregate production function, where output depends on the quantity of labour and capital, and how they combine (i.e., technology). But aggregate capital is not measurable, nor can the aggregate production function be obtained from that of the individual firms. Micro-foundation has a rationale only if agents are not identical in tastes, endowments, rationality, and information, when there is reason to have exchange and production of goods and services (i.e., not when the economy does not exist as its agents are all identical). *Mainstream* theories of capital cannot have an unambiguous theoretical measure of aggregate capital since it depends on the variable that capital is supposed to determine: the profit rate. It is impossible to give capital a measure in value that is independent of the profit rate. The reasoning would be circular because to measure capital we must estimate the profit rate, which cannot be estimated without knowing the value of capital.

The general equilibrium theory was formulated by Walras (1874), and later extended by Pareto (1896–1897 and 1906), inspired by the mechanical principles of Poinsot's *Elements de Statique* (1803). This theory aims to show that in equilibrium the system is efficient and optimal. Pareto-efficient allocation is the best possible situation in terms of allocative and productive efficiency: one cannot improve the utility of one individual without worsening that of another. Pareto efficiency does not imply a socially desirable distribution of resources

© in this web service Cambridge University Press & Assessment www.cambridge.org