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## *NOTES AND TOPICS*

# Complexity Theory and Economics

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Complexity theory has generated much interest in recent years. In 1993 two books on the subject were published (Lewin, 1993; Waldrop, 1993) as well as a *New Scientist* supplement (6 and 13 February), an article in *The Atlantic Monthly* (Morris, 1993) and at least two pieces in the Australian national press (McGuinness, 1993; Toohey, 1993). Its ideas are being presented as fundamental to our understanding of all kinds of physical and social phenomena, including economics; and some commentators (e.g. Arthur, 1988) use it to argue for particular forms of government planning. Yet its striking affinity to the ideas of F. A. Hayek and the Austrian School generally suggests that modern complexity theory actually tends to bolster arguments *against* government planning.

## What Is Complexity Theory?

Complexity theory stems from the study of the emergence of order in complex systems, which range from ecosystems to the evolution of species, and from the development of civilisation to the workings of a modern economy. Such systems are 'complex' in that they not only combine several elements (like the molecules of a gas) but are also *organised.* According to F. A. Hayek (1978:26-7), the features of systems that display 'organised complexity' depend 'not only on the properties of the individual elements of which they are composed, and the relative frequency with which they occur, but also on the manner in which the individual elements are connected with each other'. Complexity theory studies the process whereby some kind of order emerges that is neither imposed on the system nor is obvious from the rules that underlie it.

According to the mathematician Ian Stewart (1993:3), complexity theory is

> an attempt to explain which systems tend to increase in complication and organise themselves, why they do it, and where such behaviour fits into the

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dynamical spectrum from total order to total chaos. The aim is to develop a coherent range of techniques for understanding the complex systems that are found in nature and to codify their behaviour in a simple set of basic principles.

An excellent example of a complex system is the 'random Boolean network'. Imagine a network of 100 light bulbs, in which the state (on or off) of any light depends on the state of the two 'input' lights) it is connected to. Each light is in turn one of the input lights for another elsewhere in the network. Imagine that the connections between the lights are set randomly and that the rules determining the relationship between any light and its two input lights are based on the binary AND and OR functions. Further imagine that the rules for any particular light are also randomly set. When the network is switched on, its configuration (patterns of ons and offs) will be continually changing. To see this, imagine that we start the network with a random selection of lights on. One of the lights initially off may have a rule saying: 'if either input is on, then switch on', and so it will switch on. This change will cascade through the network as the change in the state of any one light will feed into the rules determining the states of other lights. The crucial question is: how long will it be before exactly the same patterns are repeated?

This 100-light network has $2^{100}$ (approximately $10^{30}$) possible states because each of the 100 lights can be on or off. Now if each state were to last a microsecond, it would take billions of times the history of the universe for the network to repeat the same pattern. But what actually happens when a network such as this is switched on is surprising. The network will, in a matter of minutes, settle down to one of only eight repeating cycles. The same sort of result holds for even bigger networks. A network of 100,000 elements (with around $10^{30,000}$ possible states) will settle down to one of around 370 different cycles.

This spontaneous emergence of order from a random network with potentially billions and billions of different states is the key concern of complexity theory.

## The Tools of Complexity Theory

Researchers in complexity theory have developed many tools to simulate complex systems and some have applied their findings directly to economics and other social sciences. For example, the Boolean networks described above, the properties of which were first worked out by Stuart Kauffman (1991), are stylised models designed to capture some of the features of complex natural systems including neural networks in the brain, genes regulating each other within a cell, the webs connecting coevolving species within an ecosystem, even the network of connections within an economy.

Researchers in complexity mostly work on computers, designing programs that simulate the features of the complex systems they wish to study. Like chaos theory, complexity theory is a product of computer technology. Computer simulation is necessary because the underlying mathematics of many complex systems is not well understood, making the scope of purely theoretical analysis limited. Yet purely empirical analysis of complex systems is also limited. Computer simulation analysis offers a new kind of investigation, mixing theory and empirics.

Complexity analysts have developed tools like cellular automata, genetic algorithms, neural networks and classifier systems. These are simulation techniques based on biological processes that have already found numerous applications (see for example Goldberg, 1989; Nelson & Illingworth, 1991). The classic application of genetic algorithms to social science is in Axelrod's (1990) analysis of the evolution of cooperation. Following Axelrod's computer tournaments to discover the best strategy in an iterated Prisoner's Dilemma game, genetic algorithms have been used to discover additional successful strategies and to simulate the evolution of cooperative solutions in other social situations (Levy, 1992:181-5). Genetic algorithms have also been used to simulate the evolution of money as a medium of exchange (Marimon et al., 1990).

Holland and Miller (1991) briefly survey the application of these tools to economics. They refer particularly to 'artificially adaptive agents' (AAAs), models of how economic agents collect and process information and build models that they then use to anticipate and respond to changes in their environment. They argue that models based on AAAs 'can capture a wide range of economic phenomena precisely, even though the development of a general mathematical theory of complex adaptive systems is still in its early stages' (1991:365). This approach is likely to contribute to our understanding of learning in economic behaviour and the role that evolving knowledge plays in economic equilibrium. This approach is consistent with Hayek's observation that economics is a '*meta*theory, a *theory about* the theories people have developed to explain how most effectively to discover and use different means for diverse purposes' (Hayek, 1988:98, italics in original).

## Complexity Theory and Spontaneous Order

The connection with economics is, however, stronger than many complexity theorists imagine. Indeed, complexity theory and economics appear to have the same aim: to explain the emergence of order in complex systems.

In 1967 Stuart Kauffman was told he would have to wait 20 years before anyone would take seriously the notion of spontaneous order in complex systems. But by then this idea had been well established in the social sciences for at least 200 years. Adam Smith observed the remarkable order that emerges from the millions of interactions taking place within the economy, and used his 'invisible hand' metaphor to describe the self-organising features of the economic system.

David Hume argued that the rules of property were a spontaneous order that 'arises gradually, and acquires force by a slow progression, and by our repeated experience of the inconveniences of transgressing it' (quoted in Hargreaves Heap et al., 1992:184). Some modern economists have combined game theory with Hume's ideas to explain the emergence of rules of property and other conventions (Sugden, 1989).

Carl Menger also focused on spontaneous orders, referring to the 'organic' or 'primeval' emergence of certain customs and institutions such as money. He claimed that although money may emerge from legislation, it originally came about as the 'unplanned outcome of specifically individual efforts of members of a society' (Menger, 1985:155).

Friedrich Hayek, following the classical economists and the Austrian School, placed the notion of spontaneous order and complexity at the centre of his economic and political analysis. According to Hayek, 'very complex orders, comprising more particular facts than any brain could ascertain or manipulate, can be brought about only through forces inducing the formation of spontaneous orders' (Hayek, 1973:38).

The most remarkable example of the similarity between complexity theory and economics is exemplified in the work of Kauffman and Hayek Each in his own field has independently focused on the interaction between evolution (natural selection) and spontaneous order (or self-organisation) in describing the emergence of order. A central thrust of Kauffman's work has been to add the notion of spontaneous order to the well-established idea of evolution by natural selection. Kauffman's insistence that the 'marriage of selection and self organisation' (1991:64) is essential to understanding biological systems is the same as Hayek's claim that 'what . . . I have called the twin concepts of evolution and spontaneous order enables us to account for the persistence of these complex structures, not by a single conception of one-directional laws of cause and effect, but by a complex interaction of patterns . . .' (Hayek, 1979:158; by 'evolution', Hayek means 'natural selection').

The affinity between complexity and economics suggests that the tools that complexity theory has developed will also prove useful in economics.

## Some Possible Lines of Research

Three areas of possible research arise directly from assertions made by Hayek, although they are not unique to him as each is reflected in various debates within economics.

First, Hayek was sceptical about the role statistical analysis could play in studying complex systems. The properties of complex systems depend on how individual elements relate to one other; information about particular elements cannot be replaced by statistical or aggregate information; it is therefore inappropriate to resort to representative agents, as econometrics invariably does. How significant is this criticism? Complexity theory could help answer this question by providing the tools to analyse models displaying the appropriate forms of complexity. These models could be used to generate data (production, consumption and so on) on which the performance of traditional econometric methods could be tested. Something similar to this has happened since the discovery of chaos theory; complexity theory is likely to yield a richer set of models for analysis.

Second, Hayek (1988:98) was highly critical of macroeconomics. His claim (also evident in the 'micro foundations' debates) was that it is inappropriate to relate aggregates in a causal manner. Why, in a complex system, should there be any stable relationship between aggregates that are the product of many changing relationships between individual agents? Clearly, any complex system will have emergent and aggregate properties and many of the emergent properties will in turn feed back to the behaviour of individual elements of the system. The question is how this emergent aggregate behaviour relates to the subject matter of traditional macroeconomics. Again, an appropriate model of a complex system could go at least some way towards addressing this issue.

Finally, Hayek often claimed that economics is limited to 'pattern prediction'. Mark Blaug (1993) has complained that since first stating this in 1934, Hayek never wrote anything to give an indication of exactly what we can and cannot predict in economics. But an appropriate complex-economy model would allow us to examine this issue.

## Conclusions

Complexity theory is about the emergence of order. So is economics. Complexity theory is not going to rewrite economics as we know it, because it has itself rediscovered ideas already present in economics. What it may do is provide some new tools that, when combined with economics' long history of analysing complex systems, may provide valuable complements to traditional economic research.

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