Chaos in Economics

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INTRODUCTION

Chaos theory has been an active discipline which has had a profound effect on a wide variety of fields in natural as well as social sciences (Prigogine & Stengers, 1984; Devaney, 1989; Peitgen, Jörgens, & Saupe, 1992; Guckenheimer & Holmes, 1986; Mainzer, 1996; Bertuglia & Vaio, 2005). Chaos theory describes the behavior of certain systems, which are highly sensitive to initial conditions. As a result of this high sensitivity, which manifests itself as an exponential growth of perturbations in the initial conditions, the chaotic systems behave "randomly" even though these systems are deterministic. The early applications of chaos theory include high sensitivity of weather patterns, chaotic swings in insect populations, waves in water, nonlinear behavior of electric systems, vibrations in mechanical structures, brain waves, heat beats, coupled chemical reactions, chaotic monetary economic growth, *Malthus' population theory*, and many other applications. Chaos theory is now applied to almost every branch of sciences. In many dynamic systems, even simple non-linear interactions may contain chaotic behavior.

The first discovery of *chaos* was Henri Poincaré (Peterson, 1993). When he was examining the three-body problem which essentially consists of nine simultaneous differential equations, he found that there can be orbits which are nonperiodic, and yet not forever increasing nor approaching a fixed point. The main catalyst for the development of chaos theory was the electric computer. The identification of chaos involves repeated iterations of mathematical formula, which is often impractical by hand. Computers made repeated calculations practical. In particular, figures and images made it possible to visualize these systems. An early pioneer of the theory was Edward Lorenz (1963) whose research on chaos came about accidentally when he was studying weather prediction in 1961, using a simple digital computer to run his weather simulation. He found out that a tiny difference in the initial conditions can lead to quite different weather patterns, even though according to the traditional theory the resulted weather patterns should be almost the same. Chaos was observed by a number of experiments before it was recognized. For instance, Yoshisuke Ueda identified a chaotic phenomenon as such by using an analog computer on November 21, 1961 (Ueda, 2001). Nevertheless, his supervising professor did not believe in chaos and he prohibited Ueda from publishing his findings until 1970. In December 1977, the New York Academy of Science organized the first symposium on chaos. Since then, chaos theory progressively emerged as a transdisciplinary and institutional discipline, partly under the name of nonlinear dynamic theory. Alluding to Kuhn's concept of paradigm, some chaologists claimed that this new theory was an example of such a shift.

This study shows how chaos theory has been applied to economics. Our inquiry is specially related to nonlinear studies of social and economic issues. The study is concentrated on theoretical models of economic chaos. By introducing the economic models which exhibit chaotic behavior both in discrete and continuous times in different dimensions, we demonstrate wide applications of chaos theory in different schools of economics. In particular, the paper argues that chaos theory is a basic tool for integrating various economic theories. Application 1 introduces the logistic map and examines the one-dimensional discrete growth model with population by Haavelmo and Stutzer. Application 2 identifies economic chaos

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in the disequilibrium inventory model by Hommes. Application 3 studies a long-run competitive two-periodic OLG model with money and capital. Application 4 discusses the Lorenz equations and its application to urban dynamics. Application 5 introduces the traditional optimal growth model with multiple capital goods, demonstrating the existence of periodic and aperiodic solutions of the traditional growth model. Finally we conclude the study.

BACKGROUND

Chaos theory is often considered as a part of theory of complex systems. Complex systems are characterized by nonlinear interactions between many elements. It reveals how such interactions can bring about qualitatively new structures and how the whole is related to and different from its individual components. The theory of complex systems is bringing scientists closer as they explore common structures of different systems. Scientists of interdisciplinary fields have exhibited great interests in the creation, diffusion and expansion of ideas about complex systems. The theory is becoming the focus of important innovative research and application in many areas. The hallmark of this newly developed science is an insistence on phenomena of change and on an inherent unpredictability in system evolution. It has helped scientists to correct an outmoded conception of the world. It offers scientists a new tool for exploring and modeling the complexity of nature and society. The new techniques and concepts provide powerful methods for modeling and simulating trajectories of sudden and irreversible changes in social and natural systems. Concepts such as catastrophes, *bifurcations*, chaos and fractals are not only the key words of many scientific fields, but also have literally captured the attention, enthusiasm and interest of the public. Certain common nonlinear uncertainties, patterns and processes have been identified in multiple scientific fields.

Before nonlinear science began to influence economic analysis, the history of *mathematical economics* had been characterized of linearity, unique equilibrium, and stability (Dendrinos & Sonis, 1990; Chiarella, 1990; Chiarella, Franke, Flasche, & Semmler, 2006; Rosser, 1991; Zhang, 1991; Benhabib, 1992; Medio, 1992; Asada, 1997; Authur, Holland, & Lane, 1997; Nijkamp & Reggiani, 1998; Puu, 2000). The economic systems which have these characteristics are easy to manipulate and are predictable. For instance, the Solow growth model which is the core model in the neoclassical *economic growth theory* shows that it is possible, given an initial point in the economic system, to find out the behavior of the system for all future times. The behavior of the system is orderly and does not fluctuate erratically if without external random fluctuations (Solow, 1956; Burmeister & Dobell, 1970; Barro & Sala-i-Martin, 1995; Zhang, 2005). This implies that the study of economic history is sufficient for us to know economic situations in the future, once if we can fully describe the system at a specified time in the past. Any external force or perturbation will result in a predictable change while tiny external changes have negligible effects. The standard neoclassical growth theory teaches students that if some deviations from the normal behavior are observed, it is not due to the internal economic mechanisms, but due to some external factors. Accordingly, the economic system always comes back to its predictable behavior if the external factors are known or controlled. Nevertheless, chaos theory challenges this neoclassical viewpoint about economic evolution.

The early formal chaotic models in economics are by Stutzer (1980) and Benhabib and Day (1981, 1982). Since then theoretical interests in *economic chaos* among economists have increased rapidly (Lorenz, 1993; Dechert, 1996; Shone, 2002; Rosser, 2004; Zhang, 2006). The new theory tells that once a dynamic system enters regions of erratic behavior, it is impossible to predict the future behavior of the system even when all the

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