592 LECTURE NOTES IN ECONOMICS AND MATHEMATICAL SYSTEMS

Abraham C.-L. Chian

Complex Systems Approach to Economic Dynamics

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With 40 Figures

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I wish to dedicate this monograph to my parents
Mr. Jong Hong Chian and Mrs. Pi-Sia Wong Chian

Preface

Characterization of the complex dynamics of economic cycles, by identifying regular and irregular patterns and regime switching between different dynamic phases in the economic time series, is the key to improve economic forecasting. Statistical analysis of stock markets and foreign exchange markets have demonstrated the intermittent nature of nonlinear economic time series, which exhibits non-Gaussian behavior in the probability distribution function of price changes and power-law dependence on frequency in the spectral density. Nonlinear deterministic models of economic dynamics are capable of simulating intermittent time series arising from a transition from order to chaos, or from weak chaos to strong chaos, which can explain the origin and nature of intermittency observed in economic systems.

This monograph studies complex economic dynamics based on a forced van der Pol oscillator model of business cycles. The technique of numerical modeling is applied to characterize the fundamental properties of complex economic systems which present multiscale and multistability behaviors, as well as coexistence of order and chaos. In particular, we focus on the dynamics and structure of unstable periodic orbits and chaotic saddles within a periodic window of the bifurcation diagram, at the onset of a saddle-node bifurcation and at the onset of an attractor merging crisis, as well as in the chaotic regions associated with type-I intermittency and crisis-induced intermittency, in nonlinear economic cycles. Inside a periodic window, chaotic saddles are responsible for the transient motion preceding convergence to a periodic attractor or a chaotic attractor. The links between chaotic saddles, crisis and intermittency in complex economic dynamics are discussed. We show that a chaotic attractor is composed of chaotic saddles and unstable periodic orbits located in the gap regions of chaotic saddles. Both type-I intermittency and crisis-induced intermittency are the results of the occurrence of explosion following the onset of a local or a global bifurcation, respectively, whereby the gap regions of chaotic saddles are filled by coupling unstable periodic orbits.

Nonlinear modeling of economic chaotic saddle, crisis and intermittency can improve our understanding of the dynamics of economic intermittency observed in business cycles and financial markets. In view of the universal mathematical nature of chaotic systems, the results obtained from our simple prototype model of economic dynamics can in fact be applied to more complex economic scenarios, including nonlinear spatiotemporal economic systems. Characterization of the complex dynamics of economic systems provides an efficient guide for pattern recognition and forecasting the turning points of business and financial cycles, as well as for optimization of management strategy and decision technology.

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Introduction

Economic systems exhibit ubiquitous complex dynamics evidenced by large-amplitude and aperiodic fluctuations in economic variables such as foreign exchange rates, gross domestic product, interest rates, production, stock market prices and unemployment (Hommes 2004). Traditionally, economists have studied economic dynamics using the Newtonian approach by treating the economic fluctuations as linear perturbations near the equilibrium (Scarth 1996, Gandolfo 1997, Shone 2002). The linear approach is valid only for small-amplitude fluctuations and cannot describe the complex characteristics of large-amplitude and aperiodic economic fluctuations. Large-amplitude fluctuations in economic and financial systems are indications that these systems are driven far away from the equilibrium whereby the nonlinearity dominates the system behavior; aperiodic economic and financial fluctuations are manifestations of chaos intrinsic in a complex system. Hence, a non-Newtonian approach based on nonlinear dynamics is required to understand the nature of complex economic dynamics.

In recent years, there is a growing interest in applying nonlinear dynamics to economic modeling. For example, Chiarella (1988) introduced a general nonlinear supply function into the traditional cobweb model under adaptive expectations, and showed that in its locally unstable region it contains a regime of period-doubling followed by a chaotic regime. Puu (1991) studied the nonlinear dynamics of two competing firms in a market in terms of Cournot's duopoly theory; by assuming iso-elastic demand and constant unit production costs this model shows persistent periodic and chaotic motions. Keen (1995) introduced a real financial sector and two stylized facts into Goodwin's growth cycle model; the resulting nonlinear system is able to model the complex behavior of Minsky's financial instability hypothesis, with the transition from stability to instability and possible breakdown determined by the level of economic inequality, interest rate and debt. Scarth (1996) derived a nonlinear standard aggregate demand and supply model of a closed economy consisting of IS, LM, and Phillips curve relationships, described by the logistic function which admits chaotic cycles for a range of control parameters; this model indicates that the standard practice of linear approximations in macroeconomics is a definite limitation. Brock and Hommes (1997) applied the concept of adaptively rational equilibrium to a cobweb type demand-supply model where agents can choose between rational and naive expectations, which shows that in an unstable market with positive information costs for rational expectations, a high intensity of choice to switch predictors leads to highly irregular equilibrium prices converging to complex dynamics such as a strange attractor. Rosser (2001) showed that in an integrated global ecologic-economic system a variety of chaotic and catastrophic patterns appear in the models of global warming dynamics and fishery dynamics, which complicate global policy making efforts. Hughston and Rafailidis (2005) applied a chaotic approach to develop dynamical models for interest rates and foreign exchange; they used the Wiener chaos expansion technique to formulate a systematic analysis of the structure and classification of these financial models. Many more examples of nonlinear economical modeling can be found in the books on complex economic dynamics (Puu 1989, Chiarella 1990, Zhang 1990, Brock, Hsieh and LeBaron 1991, Rosser 1991, Benhabib 1992, Medio 1992, Lorenz 1993, Day 1994, 2000, Thomas, Reitz and Samanidou 2005).

One of the main signatures of complex systems is intermittency, which is characterized by abrupt changes of the system activity with alternating periods of quiescent low-level fluctuations and bursting high-level fluctuations. Temporal intermittency and spatiotemporal intermittent turbulence are pervasive in nature and society, e.g., the flow of cars in heavy traffic in the cities, the floods and droughts of rivers such as the Nile, the fluid turbulence in atmosphere and ocean, and the sunspot cycles (Vassilicos 1995). Intermittency exhibits multiscale behavior (power-law dependence on frequency/wavenumber) and non-Gaussian statistics (heavy-tail probability distribution function of fluctuations), involving information transfer between different scales. There is evidence that intermittency is also a fundamental feature of complex economic and financial systems. For example, Müller et al. (1990) presented a statistical analysis of four foreign exchange spot