Chapter 11, Instability, Complexity, and Bounded Rationality in Economic Change*

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Abstract

Economic order and structural change can be better understood from the perspective of self-organization under non-equilibrium constraints. The constructive role of instability, prevalence of complexity, and source of bounded rationality are demonstrated by examples of traffic flow, complex business cycles, economic crisis, division of labor, and economic development. The socio-economic order can only be maintained by self-organization processes.

Introduction

A central theme in equilibrium economics is the mechanism of stability and simplicity in market economy. It is believed that optimal solutions can be achieved by rational behavior including utility/profit maximization, risk aversion, and rational expectations. A fundamental problem in economics is how to understand the origin of diversity and complexity of economic systems. Increasing numbers of economists are seeking solutions of many economic puzzles, such as irregular and recurrent business cycles, diverse patterns in economic growth, hysteresis and path-dependence in innovation and structural changes.

The equilibrium view of neo-classical economics is parallel to the ideas of mechanical stability and thermodynamic equilibrium in classical physics. According to this perspective, economic order is characterized by self-convergence or a tendency towards equilibrium. Economic problems such as unemployment and crisis are in the temporary disequilibrium caused by external shocks. Various economic policies are designed on the basis of returning to equilibrium. Therefore, negative feedback is considered as the "good" mechanism

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of economic stability while positive feedback is regarded as the "bad" source of market instability. Equilibrium economics does help us understand one side of the story in economic movements: the self-correction mechanism and the tendency of convergence, but falls short of another side of the story: the self-organization mechanism and the origin of diversity.

It is true that order and difference will disappear in isolated systems according to the second law of thermodynamics when they approach equilibrium. However, economies like organisms are open systems under non-equilibrium conditions. In nonequilibrium situations, fluctuations play an essential role. Bifurcations appear and we have to go from a deterministic to a probabilistic description.

Sciences dealing with human behavior have always been influenced by the dominating paradigms in physical sciences. Now these paradigms are shifting and that will likely have a lasting influence on economic sciences [Prigogine and Stengers 1984, Prigogine 1993].

In this article, we will discuss several examples from the point of view of instability and complexity. The constructive role of instability sheds new light on the origin of economic complexity. Bounded rationality in human behavior is not only caused by external limitations of imperfect information, but also constrained by internal limitations of unstable dynamics.

Micro Irregularity and Macro Regularity:
The Case of Traffic Flow

Let us make a preliminary remark related to the description of complex systems. There are conflicting views in economic studies. One popular approach is to use a representative agent in characterizing average behavior, an equivalent of an one-body problem. Another extreme is system dynamics in terms of a large number of variables. The complexity of human interaction may not be fully grounded on individual optimization. Can we understand complex systems in terms of relatively few variables?

An interesting example of the reduction of a complex problem to few variables is traffic flow. In the case of single-lane traffic flow without passing, observational data of car-following behavior can be described by the stimulus-response equation with a time delay, T. We have the following continuous-time difference-differential equation [Chandler, Herman, and Montroll 1958, Herman et al., 1959, Herman 1993]:

$$d^2X_n(t+T)/dt^2 = \lambda[dX_{n-1}(t)/dt - dX_n(t)/dt] \quad (1)$$

where X_n denotes the coordinates of the n-th vehicle.

In the case of multiple-lane traffic flow, the Boltzmann-type kinetic equation is introduced to describe the evolution of a speed distribution [Prigogine and Herman 1971].

$$df(x,v,t)/dt = \partial f/\partial t + v\, df/dx = -(f-f_0)/T + (1-P)\, c(x,t)\, (\bar{v}-v)f \quad (2)$$

where v is velocity, f(x,v,t) is the velocity distribution function, f_0 the desired speed distribution, c(x,t) is vehicle concentration, T the relaxation time, P the probability of passing, and $\bar{v} = \int vf\, dv/c$, the average speed. We need to solve the nonlinear continuous-time integro-differential equation. At low concentration, the driver’s desired speed can be realized. But as the concentration increases, the driver's speed will deviate from the desired speed more and more.

To explain the observed patterns of moving and stopping cars in town traffic, a "two-fluid model" has been developed [Herman and Prigogine 1979].

These models can be verified quantitatively with empirical data. Unlike linear econometric models, more sophisticated mathematical models are used in traffic flow. The nature of the local interacting mechanism is an essential part of the aggregate problem.

Comparing traffic models with econometric models, several considerations may arise for economic modeling. First, the popular assumption of i.i.d. (independent identical distribution) in econometrics is not relevant under the changing environment of concentration and speed. Second, the expectation distribution is subject to change due to people's interactions. There is little chance for rational expectations with perfect foresight in the traffic situation. Third, a difference-differential equation can be approximated by large systems of differential equations, but cannot be approximated by low-order difference equations.

Long Correlations and Complex Cycles:
Strange Attractors in Economic Movements

In neo-classical economics, economic order is described by a fixed point or periodic cycles. In most econometric models, economic dynamics is characterized by linear stable systems driven by external noise.

From a wide range of empirical data of economic aggregates, we have found clear evidence of nonlinear mechanisms including complex patterns of phase portraits, long serial correlations, stable fundamental frequencies, and low correlation dimensions [Barnett and Chen 1988, Chen 1993a, Wen 1993]. It is widely believed that the monetary movements are the main sources of external shocks and stock price changes follow a random walk. We have identified substantial evidence of continuous-time chaos from monetary and stock price movements [Chen 1988, Wen 1993, 1995]. The role of time scale and observational reference is critical to recover deterministic dynamics from noisy data with growing trends. Complex business cycles can be better described by strange attractor than by harmonic cycle or random walks.

In physics, the role of chaos came as a surprise, as chaos leads to a probabilistic behavior while the basic equations are deterministic. This does not apply to human behavior as there are no "Newtonian equations" on the level of individual behavior. Human decisions depend on the memory of the past and anticipation of the future. Moreover, a condition associated with chaos - sensitivity to initial conditions - is obviously satisfied in most human activities. As the result, we expect "chaos" type of behavior to be prevalent in human sciences, including economics.

Business Cycles and Rule-Induced Expectations:
Freeway Models and Soft-Bouncing Oscillators

In economics, the harmonic oscillator and the exponential growth represent two polar linear models. Nonlinearity is introduced by resource limitation in the logistic model. In economic theory, various nonlinear limitations are considered. Examples are: the floor and ceiling in investment, monetary control, and exchange rate target. The problem of quadratic or the piece-wise linear model is the rigidity in boundary specification. Hard boundary is rarely observed in human behavior. A typical case is the upper and lower speed limits for American "freeway": no one exactly follows the rule, but few drivers can ignore the rule without the risk of punishment. The theory of rational expectations in equilibrium economics asserts that people in average make no mistakes in economic forecasting, so that rational behavior based on perfect information is the very foundation of market stability. The model of rule-induced expectations is based on empirical observations that people's expectations are shaped by mass psychology as well as institutional arrangement. Changes of collective expectations can be a major source of market instability and economic innovation.

In studies of monetary cycles and stock price movements, we have developed a family of "freeway" models [Wen 1993, Wen, Chen, and Turner 1994, Wen 1995], based on the following simple model of "soft-bouncing oscillator" [Chen 1988] :

$$dX(t)/dt = aX(t) - b\,F(X(t-T)) \quad (3)$$

$$F(X) = X \exp[-X^2/\sigma^2] \quad (4)$$

$$G(X) = X\,[1-(X/\sigma)^{\mu}] \quad (5)$$

where X is the deviation from the desired (equilibrium) state, T, the time delay. F(X) is the control function with soft-boundaries, which is differed with G(X) with hard-boundary in the case of logistic model.

This equation can be compared to equation (1) for traffic flow. Both equations predict instabilities. In particular, equation (3)-(4) may have chaotic solutions characterized by positive Liapunov exponents.

The observed low-dimensional attractors and long-term correlations can be well described by these models. The soft-bouncing oscillator can be used as a building block in economic modeling, an intermediate model between periodic motion and random walk. For example, the stock market prices can be well simulated by the two-variable freeway model, as shown in Fig. 1 [Wen 1995].

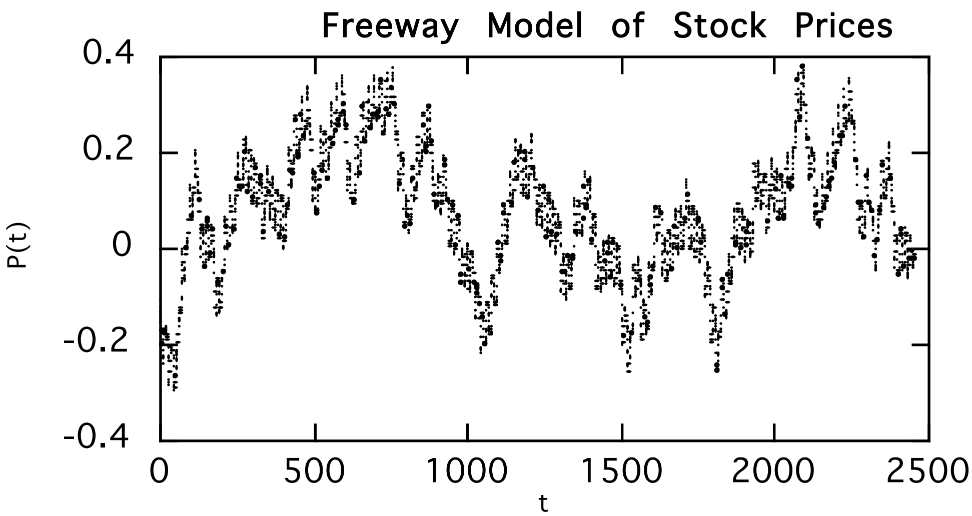


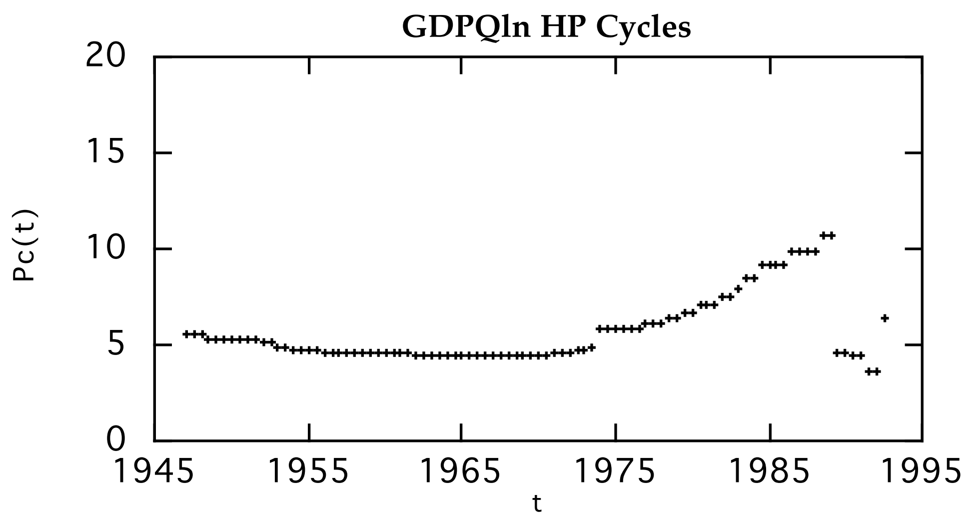
Fig.1. The chaotic time path of the 2D freeway model [Wen 1995].

Local Instability and Global Stability:
The Case of Oil Price Shock and Stock Market Crash

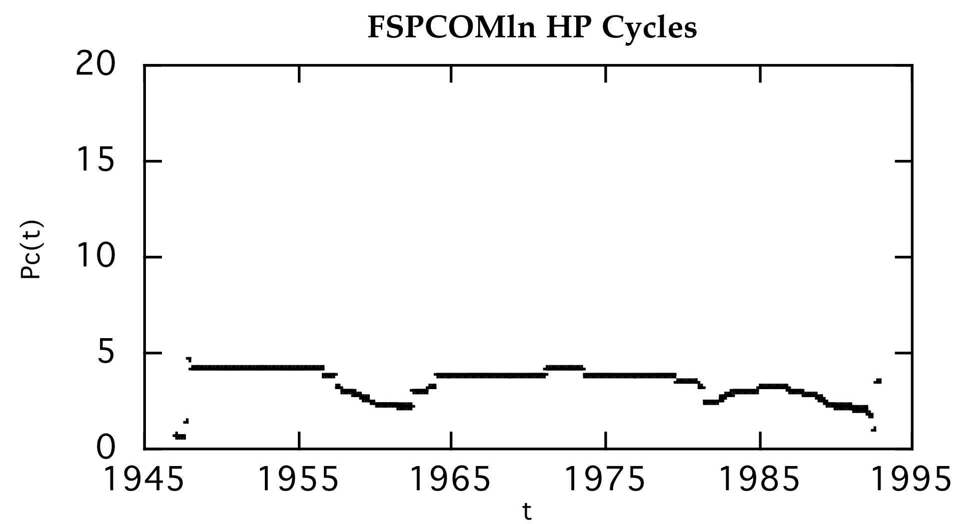
A fundamental difficulty in analyzing economic time series is the nonstationary nature of economic aggregate data. Conventional tools of correlation analysis and spectral analysis are not capable of detecting structural changes, because they are based on the assumption of stationarity. The recent progress in time-frequency analysis provides a powerful tool in analyzing nonstationary time series [Qian and Chen 1994, Chen 1994, 1995].

Under the time-frequency representation, most economic indicators have stable characteristic frequencies like oscillating chemical reactions, or living organisms. The evolution pattern of these characteristic frequencies reveals new information about the sources of economic instability and structural changes.

A notable example is the oil price shock. It is speculated by econometricians that a major trend break in real GDP is caused by the oil price shock [Perron, 1989]. This conjecture is directly confirmed by our time-frequency analysis, since the breaking point coincides with the date of the oil price shock in October 1973.



(a). Time evolution of characteristic period P_c of GDPQ (Real Gross Domestic Products Quarterly) HP cycles. N=184.



(b). Time evolution of characteristic period P_c of FSPCOM (Standard & Poor Stock Price Monthly) HP cycles. N=552.

Fig. 2. Frequency stability and time evolution in history (1947-1992). These time series are detrended by Hodrick-Prescott filter [Hodrick and Prescott 1981]. The changing pattern of characteristic period Pc is a useful indicator in economic diagnosis. Impacts of economic policies and historical events such as war and crisis can be quantitatively observed from changes of "economic pulse."

However, the stock market crash tells another story of endogenous changes. From the time-frequency analysis, we can see that the market instability emerged as a small bump in characteristic frequency during early 1987 to the end of 1987. The stock market crash in October 1987 happened near the end of the 12-month frequency shift. The frequency recovered 2-month later after the crash. This suggests that the stock market crash is the result of internal instability instead of the external shocks.

Surprisingly, market resilience is remarkable since most characteristic frequencies are very stable against external shocks and internal instabilities [Chen 1994, 1995].

Innovation, Differentiation, and Order through Fluctuation:
The Origin of Division of Labor

Pattern formation, as it occurs in chemical reactions, is the result of bifurcations. Fluctuations play a dominant role. We may also consider innovation and "creativity" as the result of "hopeful" fluctuations which correspond to deviations from the "average" behavior. Pattern formation occurs on macroscale as well [Nicolis and Prigogine 1977, 1989, Prigogine 1980].

Notable examples are the auto industry in Detroit and the computer industry in the Silicon Valley. Increasing return to scale and path-dependence are economic terms of nonlinearity and irreversibility in economics [David 1985, Arthur et al., 1987, Krugman 1991].

The equilibrium outcome of price competition is formulated by the static optimization model in neo-classical economics. Non-price competition such as competition for natural resource or market share can be explicitly described by the dynamical competition model in theoretical biology [Nicolis and Prigogine 1977, Chen 1987]. Geographical patterns of urban development are a vivid example of self-organizing processes [Allen and Sanglier 1981]. The origin of division of labor and the trade-off between stability and prosperity can be understood by learning and competition under changing environment such as technology revolution and resource expansion [Chen 1987, 1991].

Bounded Rationality and Decentralized Experiment:
The Case of China's Economic Reform

The rise of the Japanese economy has puzzled many economists by its unorthodox economic policy. China's successful economic reform is another "anomaly" of the conventional economic wisdom [Singh 1991].

Why is it that a decentralized, bottom-up, experimentally based approach to reform brought China institutional change at a much lower social cost than reforms elsewhere?

Big-bang proponents like to argue that "you cannot leap over a chasm in two steps." Chinese reformers counsel instead that "you can only walk across a river by feeling first for the stones." This clash of metaphors reflects a difference in the underlying paradigms. The former approach, based on the Newtonian paradigm of classical mechanics, believes that after the shock therapy knocks the economic system out of the orbit provided by central planning, the forces that move individual markets toward an equilibrium position can and will steer the entire economic system into a new, stable regime. This approach reflects the underlying paradigm of modern economics - an equilibrium-oriented approach that says, "Get the prices right, and the rest will follow." But in reality, social change is a complex, path-dependent, and unpredictable process. Great uncertainty exists during the bifurcation and transition stage. This uncertainty translates to a high risk of expensive errors when coupled with the high cost of any social restructuring. Therefore, decentralized experiments will have less uncertainty in social changes and more opportunity of institutional innovations [Chen 1993b].

Equilibrium economics mainly focuses on the stabilization policy in a market economy. The nonequilibrium perspective gives more weight to growth and development as a self-organization process. The discovery of a limited predictability in the time path and bounded rationality caused by unstable dynamics is further improving our understanding of the real world [Prigogine 1993].

In a recent report to the European Communities, C. K. Biebracher, G. Nicolis and P. Schuster wrote (private communication): "The maintenance of the organization in nature is not - and can not be - achieved by central management; order can only be maintained by self-organization. Self-organizing systems allow to adapt to the prevailing environment, i.e. they react to changes in the environment . . . which makes the systems robust against perturbations . . . ."

This conclusion we believe is of importance in economic sciences.

Summary

The design of economic policy is based on our understanding of economic dynamics. From the perspective of equilibrium economics, the ideal state of economies is perceived as the steady state with Gaussian deviations. There is no place for innovation, creativity, or structural change, since they are "anomalies" under the equilibrium perspective. The shortcomings of equilibrium economics are visible in the difficulties in the understanding of the causes of business cycles, the origins of division of labor and so on.

The new perspectives of self-organizing economics under non-equilibrium constraints emphasize the constructive role of instability and complexity in economic dynamics and economic evolution that leads to. New methods of analytic analysis and theoretical modeling which provide better tools of economic analysis and forecasting.

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Bibliographical Sketch

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Kehong Wen, Post Doctoral Fellow at the Ilya Prigogine Center. He entered in 1982 the Modern Physics program of the University of Science and Technology of China. After graduation in 1987 and receiving Bachelor of Science degree, he came to the University of Texas at Austin through the CUSPEA program directed by Professor T. D. Lee. He first worked on simulation of complex chemical reactions, then shifted his focus to applying nonequilibrium statistical physics and nonlinear dynamics to economic problems such as business cycles and stock market dynamics. He received Ph.D. in physics from the University of Texas at Austin in 1993. Ongoing research includes studying the development strategy of China's economic reform from the point of view of economic self-organization.