Economic Complexity and Equilibrium Illusion

The Principle of Large Numbers indicates that macro fluctuations have weak microfoundations; persistent business cycles and interrupted technologies can be better characterized by macro vitality and meso foundations. Economic growth is limited by market extent and ecological constraints. The trade-off between stability and complexity is the foundation of cultural diversity and mixed economies. The new science of complexity sheds light on the sources of economic instability and complexity.

This book consists of the major work of Professor Ping Chen, a pioneer in studying economic chaos and economic complexity. The chapters are selected from works completed since 1987, including original research on the evolutionary dynamics of the division of labor, empirical and theoretical studies of economic chaos, and stochastic models of collective behavior. Offering a new perspective on market instability and the changing world order, the basic pillars in equilibrium economics are challenged by solid evidence of economic complexity and time asymmetry, including Friedman's theory of exogenous money and efficient market, the Frisch model of noise-driven cycles, the Lucas model of microfoundations and rational expectations, the Black–Scholes model of option pricing, and the Coase theory of transaction costs.

Throughout, a general framework based on complex evolutionary economics is developed, which integrates different insights from Smith, Malthus, Marx, Hayek, Schumpeter, and Keynes and offers a new understanding of the evolutionary history of division of labor. This book will be of interest to postgraduates and researchers in Economics, including macroeconomics, financial economics, advanced econometrics and economic methodology.

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Economic Complexity and Equilibrium Illusion

Essays on market instability and macro vitality

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Contents

Part I

Methodological review

Economic complexity, equilibrium illusion, and evolutionary dynamics

2 Equilibrium illusion, economic complexity, and evolutionary foundation in economic analysis[1]

The flying arrow is at rest.

(Zeno of Elea (about 490–425 BC) in Plato 1997)

The all is one.

(Zeno of Elea (about 490–425 BC) in Aristotle 2008)

The way gave birth to unity, Unity gave birth to duality, Duality gave birth to trinity, and Trinity gave birth to the myriad creatures.

Lao Tzu (about 600–500 BC) (Lao Tzu 1990)

2.1 Introduction

It is widely believed that the idealized world without friction is a unifying foundation for equilibrium economics. This belief faces fundamental challenges from new findings in complexity science, which will lead to a paradigm shift in economic thinking and quantitative analysis.

Two basic models in equilibrium economics are the optimization model and the representative agent, which are based on a Hamiltonian framework in economic theory. The Hamiltonian approach is valid only for a conservative system without friction, i.e., no energy dissipation in the form of heat. Notable examples in physics are planetary motion and harmonic waves, including electromagnetic waves and the atomic spectrum. Two economic features go beyond the scope of the Hamiltonian system: business fluctuations and economic growth. Specifically, the building block in econometrics is random noise, which is the typical feature of energy dissipation or entropy production. In other words, an economic system is more like a biological system than a mechanical system, since they are dissipative systems not Hamiltonian systems in nature.

According to nonequilibrium physics, potential function no longer exists under far from equilibrium conditions, which indicates the limit of the optimization approach (Prigogine and Stengers 1984). Nonlinear dynamics told us that nonlinear interaction is the internal deterministic cause of seemingly random movements, an alternative mechanism for external explanation of business cycles. Positive feedback is a constructive force for growth and innovation, which is outlawed by equilibrium economics under the equilibrium condition of non-convexity. The many-body problem (such as social behavior) is essentially different from the one-body (in a representative agent) and two-body (in bilateral bargaining) problems. If we accept these new understandings in complexity science, we will easily realize that many doctrines in mainstream economics are simply equilibrium illusions, which are equivalent to perpetual motion machines against the laws of physics and the history of division of labor.

In this review chapter, we will examine two central beliefs in equilibrium economics: the self-stabilizing market and institutional convergence. We will see that both computational and natural experiments demonstrate the limits of the equilibrium approach and the potential of an evolutionary perspective based on a nonlinear and nonequilibrium approach.

In section 2.2, we give a brief review of how technical progress in complexity science led to a paradigm shift in economic thinking. In section 2.3, we discuss equilibrium illusions in economics and econometrics. In section 2.4, we demonstrate the main results of computational experiments in testing competing economic theories. In section 2.5, we study transition economies and their implications to economic theories. In section 2.6, we address fundamental issues to be solved by the next generation of economists. We hope that a new dialogue between scientists and economists will be fruitful in bridging the gap of two cultures, i.e., the mechanical and living world.

2.2 From methodological debate to fundamental thinking in economic complexity

The strong link between mathematical simplicity and equilibrium thinking is a major source in economic controversies. I would like to share my own experience with fellow scholars in a dialogue between complexity scientists and equilibrium economists.

I was trained as an experimental as well as theoretical physicist. When I began searching for empirical evidence of economic chaos in 1984, I had no idea about conflicting economic schools of thoughts. After we discovered empirical and theoretical evidence of monetary chaos and color chaos from stock market indexes (Chen 1988a, 1996a, b), our discoveries received a warm response from physicists, biologists, Austrian and Keynesian economists, but a cool reaction from mainstream economists and fierce opposition from econometricians.

On the surface, most debates were concentrated on technical issues, such as noise vs. chaos, linear vs. nonlinear detrending, deterministic vs. stochastic models, etc. After more technical progress, the central debate shifted to basic issues in economic order. Why are mainstream economists more reluctant to accept simple mathematic ideas of nonlinearity and complexity? In addition to mathematical difficulty, we found that equilibrium economists hold a fundamentally different view of life and order. For physicists and biologists, life is better described by cycles rather than noise. The so-called chaos model is simply a more general model of the nonlinear oscillator, which is visible from the biological clock. Brownian motion only plays a minor role in ideal gas without interactions. But for economists believing in laissez-faire policy, the normal economic order is a static equilibrium state plus small random noise. We went back to check if equilibrium assumptions had any empirical foundation. Three discoveries changed our view of equilibrium theory: the so-called Frisch model of noise-driven cycles in econometrics was quietly abandoned by Frisch himself in 1934 and it was a perpetual motion machine in nature (Chen 1999, 2005); the Lucas model of microfoundations had weak evidence according to the Principle of Large Numbers (Chen 2002); and the Coasian world of zero-transaction costs was another perpetual motion machine in economics (Chen 2007a). We finally realized that market fundamentalism was a pretty toy in math modeling but just a theoretical illusion in biophysics and economics.

The transition from classical mechanics to relativity theory may provide an enlightening lesson for economists (Galbraith 1994). After the Michelson–Moley experiment failed to detect ether-drift, Dutch physicist Hendrik Lorenz made a technical modification (such as space contraction and time slowdown under high speed movement) to preserve the ether hypothesis, but Albert Einstein made a simple revolution by giving up the ether hypothesis and introducing special relativity. Before Einstein further developed general relativity, scientists widely believed that Euclidean geometry was the only choice for geometry in the real world. But Einstein taught us that there were infinite possibilities of non-Euclidean geometric systems. Which geometry is relevant to our world is an empirical issue, which should be free from constraints in ideology or aesthetics.

Today, economics faces a similar situation to classical physics, or more exactly, astronomy before Copernicus. It is widely believed among economists that equilibrium economics provides a consistent framework in economics, which is capable in explaining almost everything from demand and supply in micro, money and unemployment in macro, corporate finance and asset pricing in finance, even firms and law in institutional economics. There seem only two clouds in the sky: the persistence of business cycles and the recurrence of conflict and war. However, mainstream economists have a good reason to ignore the minority camp on the grounds that heterodox economics is underdeveloped, simply because they rarely use elegant math models as their main language.

Things have changed since the emergence of the new science of complexity. We will see that the equilibrium perspective is challenged by the evolutionary perspective not only by historical and philosophical arguments, but also by theoretical and mathematical analysis.

2.3 The economic beliefs and equilibrium illusions in economics

The development of nonequilibrium thermodynamics and the discovery of deterministic chaos radically changed two basic beliefs in sciences. First, there is a fundamental difference between Hamiltonian and dissipative systems: the former system is reversible and the latter is irreversible while all living and social systems are dissipative system in nature. Second, predictable trajectories in classical mechanics rarely exist in real dynamics when dynamic systems are non-integrable with nonlinear interactions or dealing with a many-body problem. These two discoveries have a tremendous impact on our study of economic systems, since the optimization approach in equilibrium economics is based on Hamiltonian economics, and regression analysis in econometrics is hopeful only under integrable systems.

By equilibrium economics, we mean the simplest version of neo-classical economics, including the assumption of a Robinson Crusoe economy, the optimal condition of convexity, the concept of perfect information and zero-transaction costs, and the first differencing (whitening) filter in econometrics.

In this section, we will give a brief review of where they went wrong and how dangerous they were as policy guidance for a real economy.

2.3.1 The belief in self-stabilizing markets

The central argument for laissez-faire economics is the belief in a self-stabilizing market.

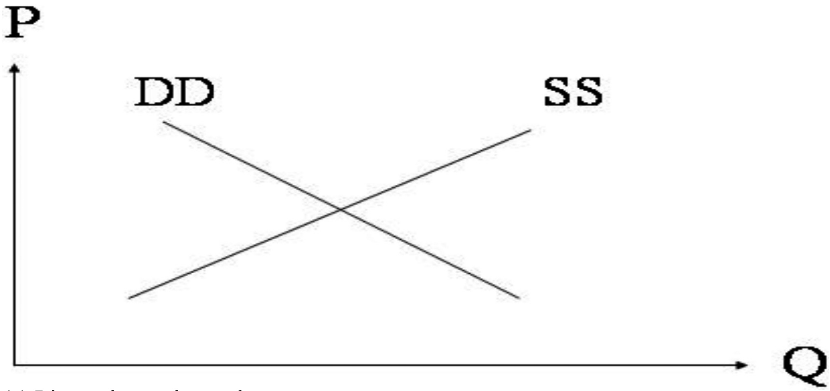
There are three basic models for portrait in self-stabilizing market: the static linear supply–demand curves; the optimization model with convex utility and production functions; and the linear stochastic model of random walk and geometric Brownian motion.

Methodologically speaking, the essential difference is between a single equilibrium state in linear models and multiple equilibrium states in nonlinear models. We will discuss linear stability in this section, and leave structural stability until section 2.3.2.

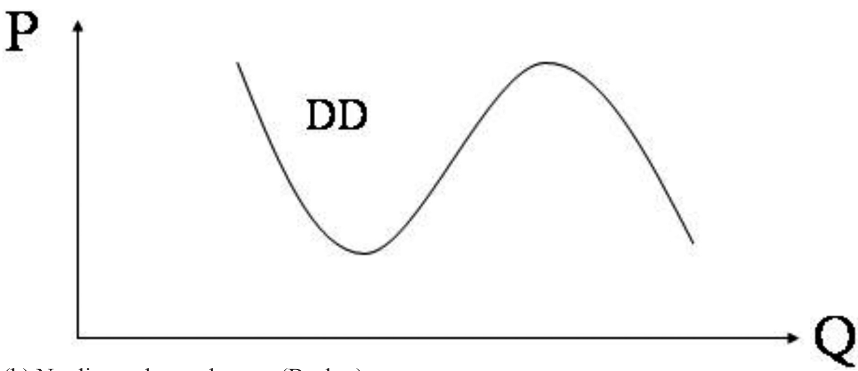
2.3.1.1 The unique equilibrium in linear demand and supply curves

The most influential illusion among economics students is the self-stabilizer characterized by negative-sloped demand curve and positive-sloped supply curve, which assures a unique equilibrium (Figure 2.1a). It is easily described by a simple diagram and derived from optimization theory under the condition of a non-increasing economy of scale (Marshall 1920; Varian 1984).

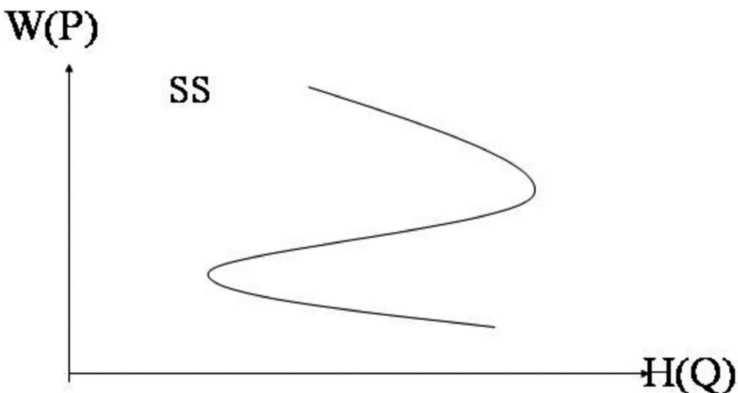
It was known that multiple equilibriums exist under nonlinear demand and supply curves. Social interactions (such as fashion and collective behavior among economic agents, Chen 1991) introduce an S-shaped demand curve (Figure 2.1b, Becker 1991). Nonlinear limitations (such as the subsistence threshold in minimum income and backward tilted curve in high wage) generate an S-shaped or Z-shaped labor supply curve (Figure 2.1c, Stiglitz 1976; Dessing 2002). Multiple equilibriums under nonlinear demand or supply curves imply the possibility of persistent cycles and sudden changes.



(a) Linear demand–supply curve



(b) Nonlinear demand curve (Becker)



(c) Nonlinear supply curve (Stiglitz)

Figure 2.1 Linear and nonlinear demand and supply curves.

Note
The market stability or instability mechanism can be characterized by unique or multiple equilibriums.

2.3.1.2 General equilibrium without non-convexity, social interactions, and product innovations

The unique stable equilibrium was created by the general equilibrium model based on maximization of utility and production function (Arrow and Debreu 1954; Debreu 1959). Advanced techniques such as the fixed point theorem in topology were used to justify the existence and stability of unique equilibrium in the Arrow–Debreu model of general equilibrium.

We should point out that the Arrow–Debreu model has its main features in a primitive economy and commanding economy, which are irrelevant to an industrial market economy. There are four basic restraints in most general equilibrium models with unique stable equilibrium. First, increasing return to scale and scope is not permitted so that market-share competition is beyond the scope of "economic rationality." Second, information diffusion and reaction does not occur among economic agents, therefore no space exists for social interactions and strategic behavior. Third, the dimension of commodity space is fixed, where no product innovations are allowed. Fourth, resource limits and market extent is ignored, which is the root of methodological individualism. All the four missing dimensions are fundamental sources of economic instability and complexity that resulted from Schumpeter's "creative destruction" (Schumpeter 1934).

2.3.1.3 The Frisch utopia of noise-driven persistent cycles: a perpetual motion machine of the second kind

During the Great Depression, Frisch invented a dynamic fantasy to save the collapsed confidence in market stability. He suggested that persistent cycles could be maintained by a stream of random shocks even with an inherently stable system. This scenario has two attractive features: first, its oscillation must be damped to rest if there are no external shocks, just like the pendulum with friction; second, it attributes persistent business cycles to external shocks, which blames economic fluctuations on external factors (bad guys or bad luck), not internal instability (so no regulation needed).

Frisch made his claim in an informal conference paper on the propagation and impulse problem (Frisch 1933). Equilibrium economists quickly embraced the Frisch model in macro, finance, and econometrics. However, physicists already knew before Frisch that harmonic Brownian motion could only generate dampened oscillation rather than persistent cycles (Uhlenbeck and Ornstein 1930). If the US business cycles could be described by the Frisch model, American business cycles would only last about four to ten years, which was not true in history. It is known that recorded history of US business cycles is more than 100 years.

The Frisch utopia implies a perpetual motion machine of the second kind, i.e., a work produced by random thermal fluctuations, or a heat engine without releasing any waste heat at a lower temperature. This engine could not exist, since it would violate the second law of thermodynamics (Chen 1999, 2005).

More surprisingly, Frisch quietly abandoned his model in 1934 but never openly admitted his mistake. Frisch claimed that he had already solved the analytical problem and that this would soon be published. His promised paper was advertised three times under the category "papers to appear in early issues" in 1933, but it never appeared in *Econometrica*, where Frisch served as the editor. Frisch did not mention a word about his prize-winning model in his Nobel speech in 1969 (Frisch 1981). Surprisingly, these facts are still ignored by mainstream economics. This story reveals an alarming truth: there is only one step between belief and illusion.

2.3.1.4 The Friedman spirits of the risk-free arbitrager for efficient market argument

A thought experiment for basic belief in a stable and efficient market was created by Friedman in discussing the self-stability of a flexible exchange rate regime. The central idea could be characterized by Friedman spirits, which were rational arbitrageurs capable of driving out irrational (destabilizing) speculators (Friedman 1953a, b). Its central message is that cyclic patterns and unstable structures could not exist in a competitive market. This is the main argument for the efficient market hypothesis in macro and finance dynamical theory.

Friedman spirits behave much like the Maxwell demon in equilibrium thermodynamics. The Maxwell demon is an imaginary gatekeeper trying to create a nonequilibrium order from an equilibrium state by operating a frictionless sliding door between two chambers that are filled with moving molecules (Maxwell 1872; Lef and Rex 1991). Maxwell assumed that his demon had perfect information about the speed and position of all molecules such that he could allow only a fast molecule into a designated chamber by opening or closing the mass-less valve in perfect timing. In economic language, under the condition of perfect dynamic information, the Maxwell demon could create a temperature difference without doing work, though that outcome is contrary to the second law of thermodynamics. The meaning of perfect information is also essential for a Coasian world with zero information costs (we will return to this issue in section 3.2.4).

Friedman spirits face a similar problem to that of the Maxwell demon but with an opposite task. To eliminate any market instability, Friedman spirits had two problems in achieving their goal.

First, resource limitation is a severe barrier in defending speculative winds with positive feedback strategy, i.e., the recurrent market fads by following the crowd (De Long *et al.* 1990). For example, foreign reserves in any central bank are limited compared to speculative capital in the global financial market.

Second, the uncertainty principle and dynamic complexity set fundamental limits in duplicating strategy in a competitive market. Friedman implicitly assumed that a winner's imitator could quickly drive down profit margins to zero. This strategy could work only if the winning pattern was replicable. There are two fundamental difficulties in doing so.

One problem is timing uncertainty in the frequency domain. The strategy of buying low and selling high works if the turning points of a speculative wave are predictable with small error. This possibility is limited by the uncertainty principle in terms of the trade-off between time resolution and frequency resolution (Brillouin 1962; Qian and Chen 1996).

Another barrier is complexity in the time domain. The sources of complexity in time series analysis include imperfect information (finite data with noise and time delays), information ambivalence (conflicting news and distorted information), unpredictable events (financial crisis and changing trends), and limited predictability (caused by deterministic chaos or wavelets). Information ambiguity is not only associated with bounded rationality but also rooted in dynamic complexity (Simon 1957; Chen 2005).

In short, there is no quantitative evidence for an efficient market. Unpredictability and ignorance do not imply market efficiency!

2.3.1.5 The whitening filter of first differencing and illusion creator in econometrics

The Frisch model of noise-driven cycles is formulated in continuous-time differential equations. The discrete-time model and difference equation are widely used in econometrics because of the mathematical convenience of regression analysis. The first differencing (FD) filter is an essential device in creating an equilibrium illusion in econometric modeling.

All scientific analysis has a common problem of noisy data resulting from measurement error and unknown factors. The general solution is developing a proper filter designed for a specific question, which is aimed at reducing noise and amplifying the signals in the form of deterministic patterns. The only exception is econometrics. The FD filter is a whitening device, which reduces signals in low frequencies and amplifies noise in high frequencies. Its frequency response function is shown in Figure 2.2, which is a sharp contrast to the band-pass filter in signal processing. Almost all illusionary evidence of efficient markets, including white noise, Brownian motion, unit root (Nelson and Plosser 1982), and co-integration (Engle and Granger 1987) etc., are created by the FD filter. In contrast, counter evidence of persistent cycles and color chaos (a nonlinear oscillator with an uneven amplitude but narrow frequency band like a biological clock) emerged through a pertinent filter, such as the HP filter with nonlinear smooth trends and WGQ filter in time–frequency space (Chen 1996a). We found that about 70 percent of business fluctuations in stock market indexes were generated by color chaos, while only about 30 percent of cyclic components were characterized by white noise. The majority of macro fluctuations are also dominated by persistent cycles rather than white noise (Chen 1996b).

The question is why econometricians are obsessed by the FD filter. The strange approach of amplifying noise was not only originated by conventional usage of percentage changes, but also rooted in the equilibrium perspective of market order. Friedman clearly realized that erratic time series resulted from the

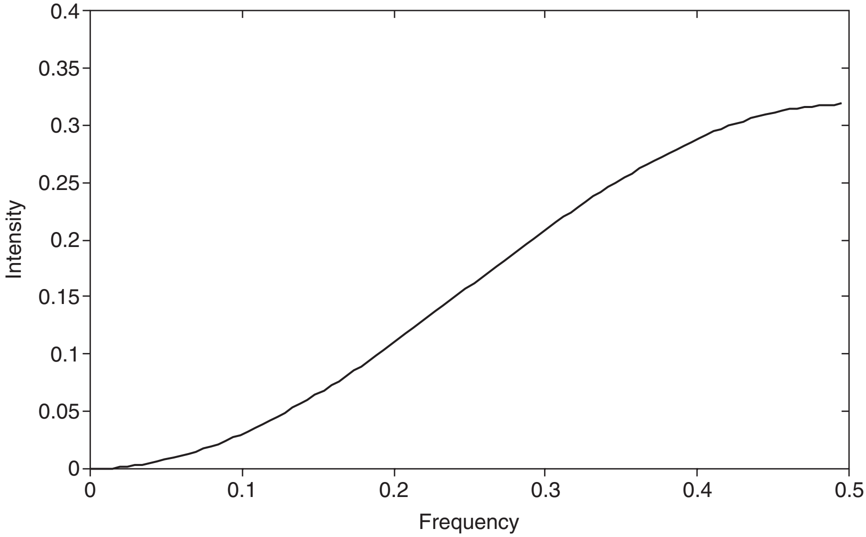


Figure 2.2 Frequency response function for the FD filter.

Notes
Here, X(t) = FD[S(t)] = S(t + 1) – S(t). The time series S(t) is in logarithmatic form. The meaning of the FD filter is conventional concept of rate of changes in a time unit. The horizontal axis is the normalized frequency range from zero to 0.5. Clearly, the frequency response function is a typical high-frequency noise amplifier. Its function is similar to the geocentric system in analyzing planet motion in astronomy.

FD filter. He defended the FD filter on the grounds that its result was independent of the choice of historical period (Friedman 1961, 1969). History does not matter, which is the core belief from equilibrium economics in constructing a Ptolemy-type representation in short-time econometrics. In contrast, Schumpeter's picture of a biological clock can only be observed from the detrending perspective, where history does matter in long-term nonstationary time series analysis.

2.3.2 The belief in social equilibrium and institutional convergence

The second argument for small government is the belief in social equilibrium where unemployment and conflicts can be solved by voluntary choice and market exchange.

We should know that social issues are a many-body problem in nature. For mathematical simplicity, economists often simplify social issues into one-body and two-body problems. Well-known models are the Lucas model of an island economy, which transformed a many-body problem into a representative agent model or one-body problem as an econometric exercise. The random walk and geometric Brownian motion in finance are also typical one-body problems, even though they are linear stochastic dynamic models. The Coase theorem is essentially bilateral bargaining, a typical two-body problem.

The critical issue is what is the fundamental difference between one-body, two-body, and three-body to many-body problems? What are the limits of these low-dimensional (one- or two-body problem) models in policy studies? We will see that social equilibrium is mainly built on a so-called Robinson Crusoe economy with just one (Robinson Crusoe) or two (in Edgeworth box) people. When you have three or more players, the social equilibrium may change into multiple equilibrium or complex dynamics. Methodologically, both atomism and reductionism assume that the whole is the sum of all the parts. When complex interactions exist between different elements, the whole is more than the sum of parts, especially for a living organism and social organization.

Two mathematical advancements shattered the illusion created by social equilibrium models based on one- or two-body problems.

For nonlinear deterministic models, chaos theory shows a fundamental difference between two-body (which can be transformed into a one-body problem with a coordinate transformation) and three-body problems (which cannot be transformed into a one-body problem and may not have any analytical solutions) in nonlinear dynamics (Hao 1990). The equilibrium state has new variants, including a limit cycle in two-dimensional dynamics and chaos in three- or higher dimensional space. For nonlinear stochastic models, complex features emerge such as U-shaped distribution, its mean may not exist, and variance can be infinite, which are beyond the scope of equilibrium economics (Chen 1991).

One essential relation between micro fluctuations and aggregate fluctuations is crucial for our further understanding the micro–macro relation: the Principle of Large Numbers provides a powerful insight in addressing micro–macro relations in quantum biology and macro economics (Schrödinger 1944; Chen 2002, 2005). One useful indicator is the relative deviation,[2] which is the ratio of the standard (absolute) deviation to the mean. For positive variables with a natural origin, such as population, price, and output, the magnitude of the relative deviation (RD) as a measure of market variability is in reverse proportion to the square root of the size of the population, see equation (2.1). Note, RD is a constant number without scale.

$$RD = \frac{\sqrt{VAR}}{Mean} \sim \frac{1}{\sqrt{\mathrm{N}}} \tag{2.1}$$

From this simple relation, we will see that the larger the micro element number N (more rigorously, N is the effective number of clusters, since micro agents may form clusters with correlations), the smaller the macro fluctuations measured by RD. This is the essence of insurance, since individual independent fluctuations may largely cancel out under large numbers. We will see that this formulation may challenge two equilibrium illusions in economic theory: the Lucas model of microfoundations and Black–Scholes model of geometric Brownian motion.

Human nature is a social animal. Equilibrium models based on a representative agency, one-body or two-body models, have severe limitations in explaining multiple equilibriums in social conflicts and evolutionary perspective in social organizations.

2.3.2.1 The Lucas fantasy of microfoundations and rational expectations

The new classical school led by Lucas launched a counter-Keynesian revolution in the 1970s. Its most powerful argument is calling for the microfoundations of macroeconomic fluctuations. Lucas suggested that independent fluctuations at the level of households (e.g., the inter-temporal substitution between work and leisure) would generate large fluctuations at the aggregate level. To achieve this claim, he used a magic device, the so-called rational expectations, which could generate a mass consensus (on the equilibrium wage rate or other mean values of macro variables) without any social interactions (Lucas 1972, 1981). The Lucas model can be easily tested by calculating America's relative deviation and take an educated guess about the number of agents according to the Principle of Large Numbers.

To our surprise, there was weak evidence of microfoundations from American macro indexes: the observed American business cycles are at least 20 times larger than the magnitude predicted by the microfoundations models in labor or producer markets. Why couldn't households with rational expectations reduce large business fluctuations in the US? Clearly, Lucas did not realize that relative prices always move in pairs. If many people choose leisure when the average wage declines, the leisure price would also go up and create an arbitrage opportunity for those who postpone leisure instead. Unfortunately, arbitrage opportunity is well known in finance literature, but does not exist in the Lucas island economy model since economic agents have no single individual degree of freedom. The Lucas island population model is a disguised representative agent model in nature (Chen 2002).

Our discovery reveals that the three-level model of micro–meso–macro is much better than two-level model of micro–macro (Chen 2002, 2005). Persistent business cycles and market instability are rooted in the intermediate structure (finance and industrial organization). This is new evidence for financial Keynesians (Minsky 1985; Dopfer 2005; Galbraith 2008).

2.3.2.2 Structural instability of the random walk and the geometric Brownian motion models as a result of the representative agent model in the stock market

One by-product of our studies in relative deviations was our discovery that the popular models in finance theory, such as random walk and the geometric Brownian motion model, are structurally unstable. They cannot explain a sustainable market over time (Chen 2005). This result paved a new way in financial theory.

It is a mathematical convention in mathematical economics that stock market fluctuations are described by a linear stochastic process. The option pricing model based on geometric Brownian motion serves as the benchmark model in the option market (Black and Scholes 1973). It is known that the geometric Brownian motion has many difficulties in financial economics. One problem is that its variance is not constant. Most modifications are still confined to the representative agent model of Brownian motion. We found out that both the random walk and the geometric Brownian motion cannot generate sustained fluctuations measured by relative deviation in stock market indexes. Fluctuations in the random walk model are dampened while those of the Brownian motion are explosive. Only the relative deviation of the birth–death process (the ups and downs are given in different "birth" and "death" probabilities within the population) is constant over time, which is capable of explaining the observed stability of relative deviations in the US macro indexes.

We developed a better alternative model of option pricing based on the nonlinear birth–death process. It could explain the volatility smile, herd behavior, and other complex behavior, including a unified explanation of existing models, which serve as special cases of a general theory in behavioral finance (Zeng and Chen 2008). The recent sub-prime mortgage crisis in US may stimulate us into rethinking the unstable nature of the Black–Scholes model in option pricing.

2.3.2.3 Monetary neutrality and the Ricardo device: a fiction without conflicting interests

One critical issue in monetary economics is the existence of the neutrality of money. We found empirical and theoretical evidence of monetary chaos, which was evidence of an endogenous mechanism of monetary movements (proposed by the Austrian school), but a challenge to the exogenous monetary theory believed by the monetarist school (Barnett and Chen 1988; Chen 1988a).

The Ricardo device is a thought experiment to justify the neutrality of money. It is a hypothetical operation of doubling overnight the cash holdings of all business enterprises and households without changing relative prices. It means that all supply and demand functions are a homogeneous function of zero degree, which is the basic argument against Keynesian economics (Leontief 1936).

In the history of scientific thought, the Ricardo device in economics is very similar to the Loschmidt reversibility paradox in physics, which was designed for challenging Boltzmann's H theorem of thermodynamic irreversibility (Brush 1983). Loschmidt argued that one should be able to return to any initial state by merely reversing the velocity of all molecules under Newton's law. The trouble here is the huge coordination costs. Boltzmann pointed out that the possibility of reversing all the initial conditions is very unlikely in dealing with a large system with many particles.

One important lesson is that macro changes are almost always an irreversible process. To reverse the macro movements imply infinite coordination costs. This lesson should be useful when we further address the next issue of transaction costs.

In political economy, the Ricardo operation implies regressive taxation. The symmetry-breaking between consumption and investment will introduce irreversibility and history in socio-economic changes. The Ricardo operation may face tremendous opposition both in regressive policy and coordinating costs. Later in section 2.5.1.1, we will see the real costs of Germany's monetary union in 1990 (Münter and Sturm 2003).

2.3.2.4 The Coase world with zero-transaction costs

Coase raised fundamental questions on the firm nature and market solution for social conflicts (Coase 1937, 1960, 1990). Coase pushes equilibrium economics beyond its traditional boundary, so we have a good chance to study the limits of neo-classical economics.

In fact, more confusion than inspiration was caused by the vaguely defined transaction costs, the ill-formulated Coase theorem, and the false analogy of a frictionless world in physics. There are many problems with the concept of transaction costs in economics.

First, there is a mismatch in time scale and analytical unit: a transaction occurs in micro with a short time window between economic atoms while organization and institution are observed in macro with a long time window. Clearly, the Coase approach is an extreme reductionism, similar to Ostwald energism in late nineteenth century physics, i.e., a theory against matter structure. The size of the firm cannot be determined solely by internal balance between transaction and coordination cost. The competitor's scale and the size of the market niche are the basic constraints related to the size of the firm or species (Schmidt-Nielsen 1984; Stigler 1951; Chen 2007a).

Second, the concept of transaction costs is vaguely defined and hard to measure, which is unsuitable to serve as any guidance in decision making. The core of transaction costs are information costs. For past information such as search costs that are limited, so that its measurement is operational. But for future information costs such as ministering and enforcement costs are explosive in time and could not be measured and served as policy guide. Coase made a hidden assumption that market competition would drive down transaction costs. He seems to ignore counter business strategies such as marketing and licensing for expanding market share at the cost of increased transaction costs. Technological progress may reduce the unit transportation cost and communication cost. However, aggregate transaction costs as a whole had a clear increasing trend in the history of the industrial revolution and division of labor, which was driven by increasing network complexity and innovation uncertainty. For example, transaction costs in the US GDP increased from about 25 percent in 1870 to more than 50 percent in 1970 (Wallis and North 1986).

Third, the Coasian world of zero-transaction costs cannot exist in the real world since it violates several basic laws in physics. The analogy between a frictionless world in physics and the Coasian world with zero-transaction costs is wrong, since zero friction is a realistic abstraction for a theory of planetary motion in space, but zero-information cost is impossible according to the uncertainty principle in quantum mechanics (Brillouin 1962). Any information collection or transmission requires some form of minimum energy. The Coase belief of reducing transaction costs in social evolution is simply against the second law of thermodynamics, since entropy production increases in biological and social evolution. The Coasian world is another example of a perpetual motion machine in equilibrium economics (Chen 2007a).

Fourth, the Coase theorem implied that institutional changes would converge to an optimal system regardless of initial conditions. This is a mechanical view of the world without history. The emergence of life and social organization is characterized by a time arrow or symmetry-breaking in a nonequilibrium process (Prigogine and Stengers 1984). Path-dependence and structural changes are essential features in legal development.

Fifth, the most controversial assertion in the Coase theorem is that any social conflicts could be resolved by bilateral bargaining without the third party (law, government, or civic society) intermediation (Coase 1960, 1990). His argument was based on the symmetry between polluter and victim, and more generally, the symmetry between consumption and investment (Coase 1960, 1990; Cheung 1998). If the Coase theorem is valid, there would be no power, no conflicts, no war, no government, and no regulations. This may be true for primitive society without private property and wealth accumulation, but is not true for a competitive but unequal market economy.

Coase made the claim of observing the real world. After careful examination, we found out that no single case studied by Coase could support his claim. Bilateral bargaining under a specific context could not converge to a (universal) optimal state when asymmetry exists in the form of non-convexity, such as scale economy in a cattle ranch, upward demand curve for pollution, and social dissent for commercial bribery. Coase argued that price theory can be applied to the externality problem if the demand curve is always negatively sloped (Coase 1990). Coase did not understand the simple reason behind the so-called downward demand curve: people usually prefer more pleasure, but less pain.

2.3.2.5 The myth of knowledge accumulation and endogenous growth without ecological constraints

The beauty of mathematical simplicity and the danger in policy implication can be seen from the recent development of the representative agent model in macro growth theory, the so-called endogenous growth theory (ENGT). It differs from exogenous growth theory (EXGT) both in math framework and in philosophy. EXGT in macro theory was started with simple macro dynamic models (Solow 1956), while ENGT led by Romer (1986) and Lucas (1988) was a representative agent model. EXGT predicts a convergence story under decreasing or constant return to scale, while ENGT predicts a divergent story under increasing return to scale. In world history, the more likely story is varying return to scale during different development stages and the rise and fall of great powers (Rostow 1960, 1990; Chen 1987a, 2005).

There are several implications in ENGT that are behind the so-called shock therapy.

First, the optimization model in macro growth theory has a strong implication of laissez-faire policy, which was an extension of microfoundations framework in new classical business-cycle theory. To some degree, the representative agent model may simply describe some stylized fact of growth levels, such as the two-sector model of transition from an agricultural economy to an industrial economy (Hansen and Prescott 2002). However, confusing growth features with "development mechanism" has a dangerous message that developing and transition economies can be guided by market forces alone without active government action (Lucas 1988). ENGT implies a limited role of governments in development. Under the knowledge accumulation and diffusion mechanism, the development mechanism is a one-way street of information flow from rich to poor countries without risk and conflicts. Therefore, the best development policy is liberalization and privatization so that foreign capital and Western institutions could freely move into poor regions. This is a main argument behind shock therapy and the Washington consensus (Sachs 2005; Williamson 1990).

Second, the concept of knowledge capital is dubious because of its stock nature in accumulation without living nature of birth of new knowledge and the death of obsolete knowledge, which is the root of recurrent unemployment and growth cycles. ENGT and the Coase approach would easily justify the shock therapy that the best development policy is a simply diffusion process without learning and innovation risk. The top-down design approach sounds similar to a commanding approach in market oriented transition.

In contrast, the evolutionary growth path is not an exponential curve but an S-shaped logistic curve, which is an alternative perspective developed in ecological biology (Chen 1987a, 2005). This can be observed from sector industrial data, such as the output ratio to GDP in the US automobile industry (Figure 2.3). The logistic curve is a typical feature for any industry or technology, including agriculture, textiles, coal, and steel.

When several technologies (industries) have overlapped in their resources or market, dynamic competition may have two possibilities: when resource competition is weak, two technologies may co-exist but at the cost of lower market share; when resource competition is strong, one technology will completely drive out the weak one, as shown in Figure 2.4. The rising technology still maintains an S-shaped logistic growth to its saturate level, but the dying technology rises and falls like wavelets (only one half of the normal periodic cycle), which are referred to as "logistic wavelets."

Several new insights can be seen from these complex dynamics in Figure 2.4. First, both business cycles and growth cycles are driven by a series of technology wavelets, which resemble the rise and fall of technologies, industries, and powers. In contrast, equilibrium growth theory is characterized by unlimited smooth growth driven by small random shocks, which obscures the dark side of

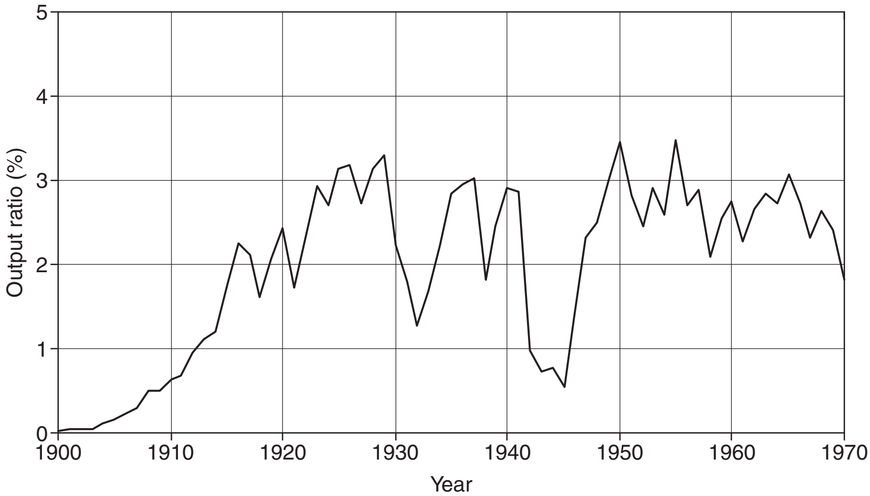


Figure 2.3 The logistic curve of the US automobile industry (source: Carter *et al.* 1997).

Note
Its output is measured by the ratio to GDP.

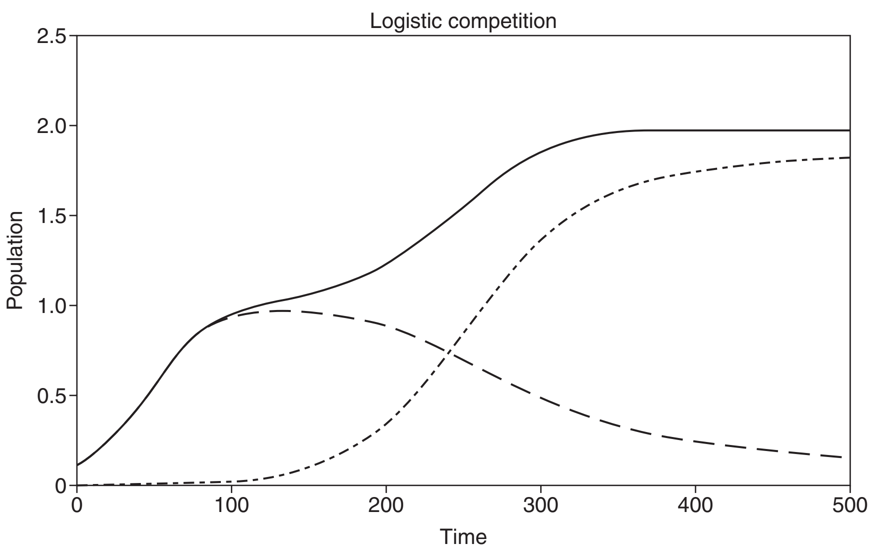


Figure 2.4 The rise of new technology and fall of old technology/industry under competition for limited resources and markets.

"creative destruction" such as persistent unemployment, excess capacities, financial crisis, and recurrent wars. Government action is needed both at the starting and declining stage.

Second, during the industrial revolution, old technology and associated knowledge is replaced by new technology and new knowledge. In this aspect, knowledge accumulation or learning by doing (Arrow 1962) is overshadowed by knowledge metabolism or learning by trying (Chen 1987a, 2005). That is why latecomers have the chance to catch and even beat early movers. This picture of changing economic powers is missing from the permanent divide between rich and poor in ENGT.

We will test these two competing approaches by transition experiments later.

2.4 Computational experiments in testing economic theories

Mathematical modeling in current mainstream economics is mainly used as a language for debate in economic policy. Is there any hope for economics as an empirical science, which can be tested by computational experiment and lab experiment? In this section, we will consider the historical events as natural experiments in time series analysis. We will focus on two central issues in contemporary economics: the inherent market instability and the diversifying trend of organizational changes.

Obviously, economics should be more complex than physics, chemistry, and biology. However, dynamical economic models are much simpler than the ideal gas model, the simplest physics model. To bridge the gap between perception and reality, we develop new algorithms based on nonlinear and nonequilibrium approaches in quantitative analysis. Mathematically speaking, econometrics analysis is mainly based on discrete-time stochastic models in a time domain, while physics and biology is mainly using continuous-time deterministic models in a frequency domain. We call our computational experiments "economic diagnosis," just like a cardiogram and X-ray scan in medicine for revealing the underlying structure of a living organism.

There are fundamental reasons in methodological differences between econometrics and physics. Econometricians favor discrete time mainly for mathematical convenience in regression analysis, whose qualitative results may change with changing time units. One typical example is the so-called unit-root model in macro econometrics, which was mainly found from annual data, but dubious from quarterly or monthly data. Physics theories have no similar problem, since major physics laws are formulated in continuous time, which is independent from time units. Another argument for stochastic models in economics is the false belief that human behavior with free will can only be described by stochastic models. This belief is visualized by the Frisch model of noise-driven cycles. Mathematically, a Fourier frequency analysis in a frequency domain can also be applied to a stochastic process. For example, white noise implies a flat spectrum and color noise a fat peak with noisy background. From quantum mechanics, we know frequency domain analysis has more information than time domain; that is why linear and nonlinear time series in frequency domain are widely used in physics, engineering, and medicine. This understanding may benefit future development in econometric analysis.

There are three facts revealed from our empirical analysis: the wide existence of persistent cycles, the statistical measure of collective behavior, and the stylized facts of technology wavelets.

2.4.1 Noisy equilibrium vs. persistent cycles

Equilibrium economics believes that market economy is self-stabilizing, which should be characterized by an equilibrium state plus some white noise, while the normal order of market economy in Schumpeterian economics considers the biological clock in the form of persistent cycles and creative destruction.

Mathematically speaking, how to characterize a moving phenomenon by a stationary model is the essence of the Copernicus problem in economics. The critical choice is the proper time window and a corresponding filter in separating trends and cycles. When we apply a short time window such as the FD filter in econometrics, we may easily get the random image of market movements. If we apply the HP filter in terms of a time window in the range of NBER business cycles, we find persistent cycles whose average period is about four to five years. Because economic data have significant component of noise, we need more advanced techniques in nonstationary time series analysis. The raw data look random, but the data filtered by a WGQ transform in time–frequency space revealed a clear picture of a continuous frequency line, a typical form of the biological clock with a stable and narrow frequency band but irregular amplitude (Figure 2.5).

The phase portrait of filtered FSPCOM (Standard & Poor 500 index) HP cycles shows a clear pattern of deterministic spirals, a typical feature of deterministic color chaos (nonlinear oscillator) in continuous time. Color means a strong peak in the Fourier spectrum in addition to a noisy background (Chen 1996a). We found out that white noise component only counted about 30 percent in stock market fluctuations. Note: many nonlinear economic models mainly concern white chaos with a flat spectrum in discrete time, such as in the case of a logistic map or Henon model (Benhabib 1992), which is rarely observed in empirical analysis since the inherent time unit is not known and fixed.

The existence of stable frequency or characteristic period was found from most macro and stock market indexes. This is convincing evidence of Schumpeter's concept of economic order as a biological clock. The history of market frequency or basic period during historical events is shown in Figure 2.6.

The time history of basic period is a new tool of economic diagnostics, which is similar to medical diagnostics in terms of heart and breathe frequencies. We can easily distinguish external shocks from internal instability, like the cases of the oil price shock in 1973 and the stock market crash in 1987. Note, here we

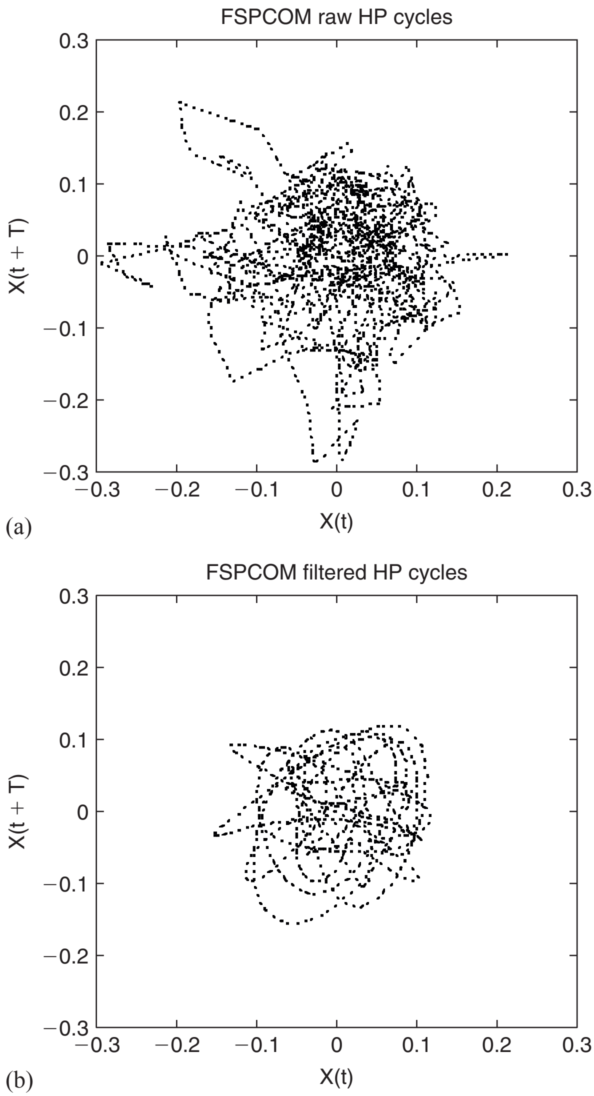


Figure 2.5 The phase portraits of the FSPCOM HP cycles.

Notes
The time delay T is 60 months. The noisy image in (a) and chaotic patter in (b) is visible from the unfiltered and filtered time series.

only use non-parametric computational experiments. Unlike regression analysis in econometrics, we simply project a complex time series on to a time–frequency space without arbitrary assumption on regression function and parameters. This is a common practice in physics and signal processing in information science. The frequency-domain analysis provides a more realistic picture that market

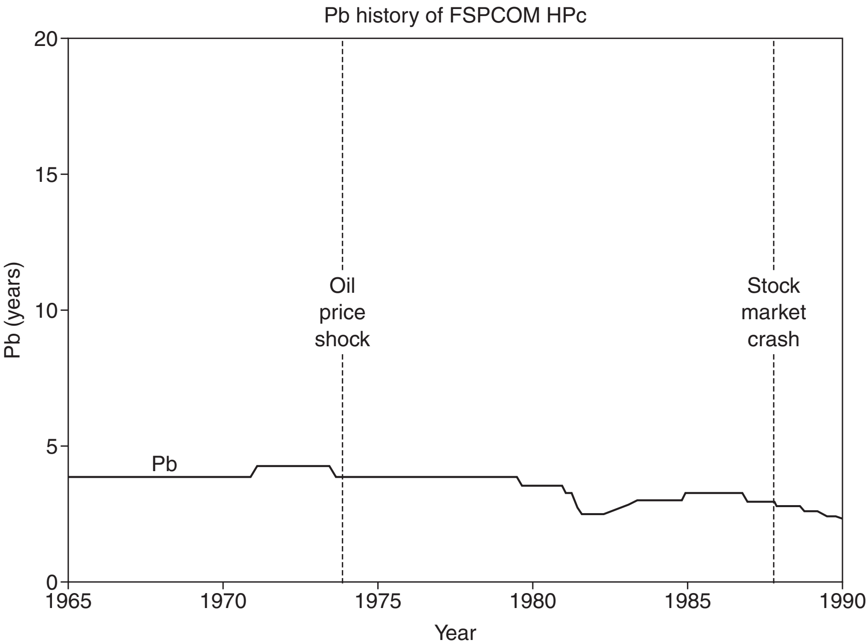


Figure 2.6 The time path of the basic period Pb of FSPCOMln (the S&P 500 stock price index logarithmic series) HP cycles.

Notes
The basic period P_b shifted after the oil price shock in October 1973, which signaled an external shock. In contrast, the frequency changes occurred before and after the stock market crash in October 1987, which indicated an internal instability during the crash.

movements can be described by a mixed picture with a dominating component of persistent cycles and a minor component of random noise.

We have to apologize for the misleading name of "chaos," which was coined by mathematicians with a negative tone of "disorder." In fact, a nonlinear oscillator or colour chaos is a higher kind of order than linear harmonic cycles. We prefer to call it "complex cycles," "persistent cycles," or "biological clock," which is characterized by local instability (also implied adjustment flexibility) but global stability, i.e., a new feature of "resilience." In contrast, white noise is the least order in math models. Economic order can be better understood by going beyond noise models in econometrics.

2.4.2 Representative agent vs. collective movements

The stable and persistent pattern of relative deviation is observed from major macro indexes (Figure 2.7). This is new empirical evidence against the representative agent model in a Robinson Crusoe economy, but in favor of a population model with collective behavior.

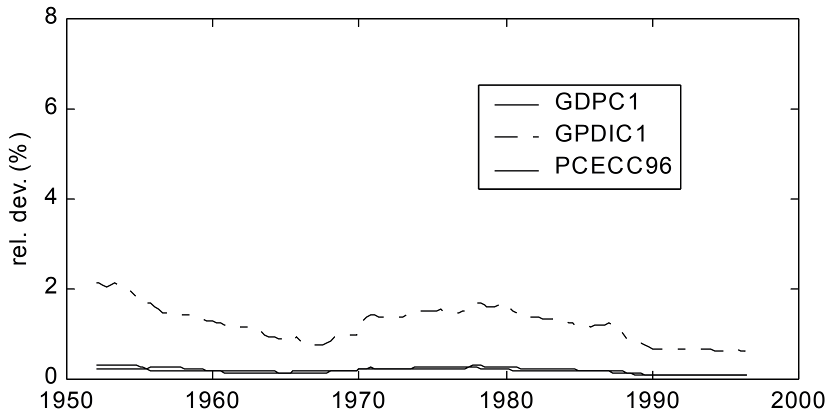


Figure 2.7 The RDs of US aggregate indexes.

Notes
Here, GDPC1 is US real GDP, GPDIC1 real investment, and PCECC96 real consumption. All series are quarterly series (1947–2001). N = 220. Moving time window is ten years. Displayed patterns were observed through the HP filter.

We can see that the damping trend (for the random walk model) or the explosive trend (for the geometric Brownian motion model) is not proper for a persistent market with constant fluctuations. Among existing stochastic models, the population model of the birth–death process provides a simple and good explanation for the stable RD pattern in a macro economy.

How can we understand the seemingly conflicting picture of persistent cycles (in section 2.4.1) and persistent fluctuations in section 2.4.2? The answer lies in the relation between complexity in reality and the complementary role of simplifying math models. A deterministic model is better for describing predictable patterns such as trajectory and periodic motion while a stochastic model is better for statistical measurement of fluctuations. The real phenomena often fall between these two simplifying models. Taking examples in physics, two extreme cases for ideal gas and ideal crystal are easy for math modeling. The fluid model and condensed matter are more difficult to model because its structure falls between these two extreme simple models. In practice, we may use a simplifying model to address some features of a complex system but take caution in its limitations.

To have a unifying picture, we may use the concept of market resilience which includes both dynamic instability in the form of persistent cycles and structural stability in the form of persistent trend.

2.4.3 Economic interruption and economic depression

We may classify a market crisis into two types: one is a large oscillation in a short time which was observed in the stock market crash in 1987 and dot com bubble in 2000; another is a long and severe economic decline, such as the Great

Depression in the 1930s and the recent Transition Depression in East Europe and the former Soviet Union (EEFSU).

We may call them disruption and depression alternatively.

2.4.3.1 Economic interruption and market resilience

When we study cases of great interruption, we are impressed by the remarkable resilience of quick recovery of market economy. The question is which model could explain market resilience after a great disruption. The American economy after World War II seems resilient under the oil price shock and stock market crash. How can we understand resilience in economic theory?

Among existing economic theories, the efficient market theory (theory of Brownian motion or random walk on Wall Street) is not qualified since an efficient market implies little possibility of large price movement or great interruption (Fama 1970, 1991).

In contrast, the theory of fractal Brownian motion theory implies high frequency of large price movements or frequent interruptions, so that it leaves little room for market resilience (Mandelbrot 1963, 1997). The popular model of unit root also has a big problem, since a small deviation from unit root in parameter space will lead to damping or explosive fluctuations (Nelson and Plosser 1982). This is a common problem in linear dynamical models including the Samuelson model of the linear accelerator-multiplier, where a periodic regime PO exists only at the border between the explosive oscillation regime EO and the damping oscillation regime DO (see Figure 2.8). So, we refer to both unit root and periodic regime as fragile stability or structural instability in linear dynamics (Chen 2005).

In contrast, structural resilience could be easily described by nonlinear dynamical models in a chaos regime. We have observed the frequency stability under large amplitude oscillations during the oil price shock and the stock market crash in Figure 2.6. This feature of a narrow frequency band and erratic amplitude can be described by the color chaos of a nonlinear oscillator in continuous time (Chen 1988a). The dynamical regimes for a nonlinear oscillator with soft boundaries in target control are shown in Figure 2.9. In addition to the linear regime of steady state (ST), there are cyclic regimes C1 (one periodic cycle), C2 (two periodic cycles), and chaotic regimes CH with complex periodic cycles (CP).

From Figure 2.9, we can see periodic and complex cycles occur in a bounded area in parameter space in a nonlinear dynamical model, not at a border line with zero area. When a parameter changes within the same regime, we may observe large amplitude changes but small frequency deviation, which resemblances the structural resilience in dynamic behavior. When parameter changes crosses the regime boundary, we will observe a qualitative change (in dynamical behavior) induced by a small change (in parameter), which is called “regime switch.” Therefore, a nonlinear dynamical model has better features of resilience with both structural stability and rapid adjustment.

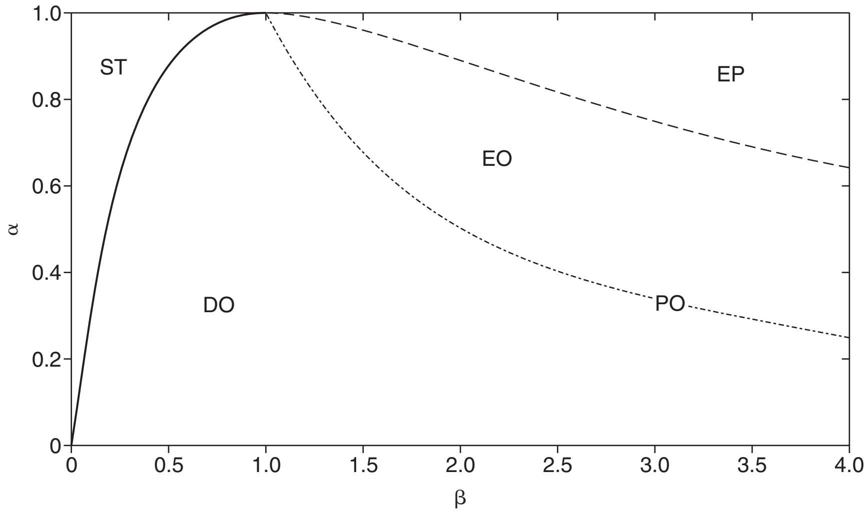
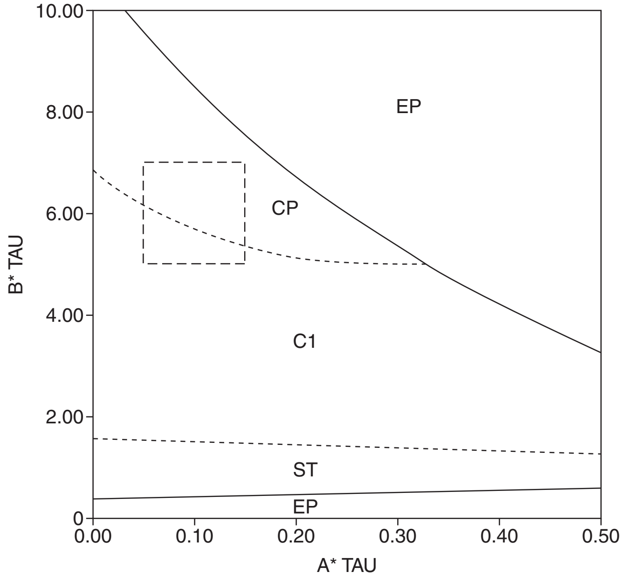


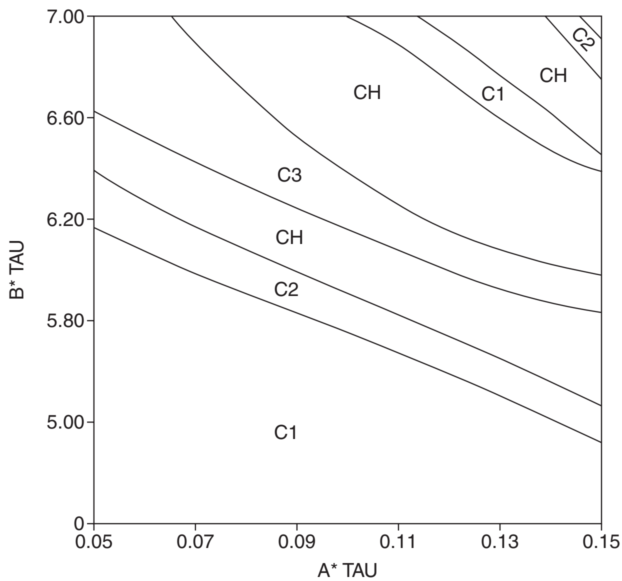
Figure 2.8 Stability pattern of the Samuelson model in parameter space (Samuelson 1939).

Notes
Here, ST denotes the steady state; DO, damped oscillation; EO, explosive oscillation; EP, explosive solution; PO, linear periodic oscillation.

We should point out that the so-called "butterfly effect" may also be exaggerated. A popular story claimed that a flap of a butterfly's wings in Brazil would set off a tornado in Texas. If this is true, it would be impossible for even a short-term, say three days, weather forecast. This claim is also a mathematical illusion without physics consideration, since it ignores the basic constraint of conservation of energy and remarkable feature of structural resilience of nonlinear dynamics under complex interactions between positive and negative feedbacks. A balanced understanding of deterministic chaos has two complementary aspects: on one side, it limits the time horizon of trajectory predictability (in the reverse order of the Lyapunov exponent or in the order of de-correlation time) and is sensitive to initial conditions (or time history); on the other hand, its behavior is more rich and resilient than linear models (Chen 1988a, 2005). Evolutionary theory in biology and economics discover two remarkable features for living organisms: their structural stability and flexibility in adapting to environmental changes. More positive terms, such as biological clock, complex cycles, persistent fluctuations, and color chaos, better describe different features of economic complexity.



(a) Parameter space for soft-bouncing oscillator



(b) The expanded regime in (a)

Figure 2.9 Stability pattern of the soft-bouncing oscillator in parameter space.

Notes
ST denotes the steady state; C1, C2, C3 are limit cycles of period one, period two, and period three respectively; CH, the chaos mode in continuous time. The complex regime CP is enlarged in (b) that includes alternative zones of limit cycles and chaos.

2.4.3.2 Meta-stability in multiple equilibriums

Game theory has a conceptual problem of how to rank different equilibrium states when multiple or even infinite equilibrium states exist. The optimization approach within Hamiltonian framework is not capable of dealing with evolutionary dynamics. The co-existence of market resilience in economic interruption and market fragility in economic depression reminds us of the concept of meta-stability in quantum biology as shown in Figure 2.10 (Schrödinger 1944; Chen 1990).

One possible scenario is that economic depression occurs during a series of shocks with complex causes, while economic disruption happens under a single shock with a simple cause. We may apply this perspective in later discussion of the Great Depression and Transition Depression.

2.5 Natural experiments: lessons from the Great Depression and Transition experiments

Now, we can further examine historical events as natural experiments or case studies in historical perspective. We will study two issues: possible causes of economic instability and crisis; and the relation between economic growth and institutional changes. We will address these questions from comparative studies between EEFSU and China in transition economies.

We should point out that there is a major difference between the Great Depression in the 1930s and the Transition Depression in the 1990s. The Great Depression mainly occurred in industrial countries under a capitalist system. The Transition Depression emerged in EEFSU, but not in China and Vietnam, even though they have a similar transition from a planned economy to a market economy.

Basic facts about the Great Depression in the 1930s and the Transition Depression in the 1990s are given in Table 2.1 (Chen 2005). We can see that the Transition Depression was more severe and longer lasting than the Great Depression. This is especially true for former republics in Soviet Union (Table 2.2).

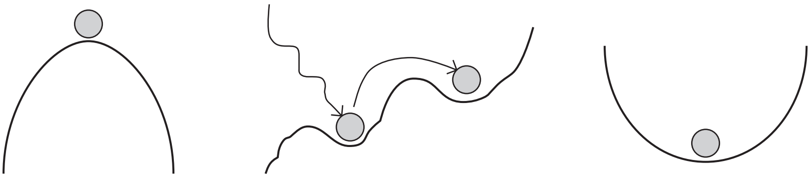


Figure 2.10 Three types of system stability.

Note
Only the meta-stable state has both the limited stability and potential variability observed in a living system.

Table 2.1 Great Depression (1929–1942) and Transition Depression (1989–2016) (decline was measured by comparing with peak level as 100%)

Country	*Decline (%)*	*Peak-trough*	*Date recovery*	*Date length (years)*
US	46.8	1929–1933	1942	14
UK	16.2	1930–1932	1939	10
France	31.3	1930–1932	1938	9
Germany	41.8	1928–1932	1933	6
Italy	33.0	1929–1933	1934	5
Japan	8.5	1930–1932	1935	6
East Europe	63.0	1989–2016	2016 (est.)	27
USSR	47.0	1989–1998		
Poland	18.0	1989–1991	1996	7
Russia	43.0	1990–1998	2007	17
Ukraine	61.0	1990–1999	2011 (est.)	21

Notes
Decline in the Great Depression was measured by industrial output (Romer 2004); and decline in the Transition Depression was measured by real GDP in constant 1990 dollar (United Nations Statistics 2008). The average recovery rate was 5.8 percent for East Europe from 1998–2006. The estimated recovery time was estimated if the future growth rate could keep 6 percent. East Germany industrial output declined 30% in 1991.

Table 2.2 Russia’s economic performance in the twentieth century (each period started with 100%)

Russia/USSR	*Period*		
	1913–1922	*1940–1945*	*1990–1996*
	WWI and CW	*WWII*	*Transition*
National Income	55.6	83.1	54.7
Industrial output	31.0	91.8	47.5
Agriculture output	66.3	57.0	62.5
Capital investment	40.3	89.0	24.3

Source: Tikhomirov (2000).

Note
CW for Civil War in Russia in 1920’s.

There were several possible factors contributing to the Great Depression: the stock market crash in 1929, banking panic, monetary contraction, first preserving then abandoning the gold standard, and the impact from World War I (Romer 2004). One puzzling fact was that the United States had the longest and the most severe depression among industrial countries, while the US had the most advantages during World War I. Clearly, economic forces, rather than political factors, played major roles in the Great Depression in US. One possible cause was industrial concentration driven by the rise and saturation of the automobile industry in the US where auto-related business accounted for about 16–18 percent of GDP in the 1970s (Rostow 1978). As seen from Figure 3.2 the American automobile industry already reached a mature stage in the 1920s. The credit contraction triggered by the stock market crash and banking crisis may have a tremendous impact on car sales.

In comparison, the recent transition depression in EEFSU revealed more clear pictures of economic depression. There are two advantages in studying transition depressions in the 1990s: first, the causes of transition depression is much simpler in theoretical analysis, since its international environment was much quieter than the situation before and during the Great Depression; second, there is a counter case of transition without depression in China, whose dual-track reform strategy provided sharp contrast with the shock therapy or so-called Washington consensus. Therefore, transition experiments provide us with a better test of competing economic perspectives in studying instability and complexity in market economies (Chen 2006). Basic facts in EEFSU and China during the economic transition from a planned economy to a market economy are given in Table 2.3.

We were surprised by the depth of the Transition Depression. The magnitudes of the Transition Depression were more severe than wars and the Great Depression in the US. More puzzlingly, China's open-door reform succeeded in very poor initial conditions with high population pressure, scarce resources, backward infrastructure, large regional disparity, low human capital, traditional culture, and underdeveloped institutions (mixed property rights and lack of rule of law). In contrast, China had sustained economic growth since 1978 at an average rate of 9 percent and increased to more than 1300 percent in 2006. How can we understand the historical events by economic reasoning?

Theoretically speaking, the shock therapy of price liberalization can be justified by the microfoundations theory in new classical macroeconomics, if the market could be characterized by unique and stable equilibrium in microeconomics. The free-trade policy is supported by ENGT if the development mechanism is a simple diffusion process by importing Western technology and institutions. The bold policy of liberalization and privatization is also encouraged by the efficient market theory and Coase approach if institutional changes would quickly converge to optimal, regardless of initial conditions. We will see how these theories are far from reality.

Table 2.3 Economic performance during the transition (each period started from 100%)

	1978	*1989*	*1990*	*1998*	*2006*
China	100	272	282	651	1327
		100	104	239	488
			100	230	471
East Europe	100	151	82.6	55.7	87.1
		100	54.7	36.9	57.7
			100	67.4	105
Russia		(100)	50.7	31.5	53.1
			100	57.4	96.6

Source: United Nations Statistics (in constant 1990 dollar). Russia (1989) was estimated from USSR (1989).

2.5.1 Instability and complexity in price mechanism

Price mechanism is the central issue in economics. Belief in price stability is certainly behind the liberalization policy in price and foreign trade in EEFSU, while dual-track price system during China's transition was aimed at avoiding price instability. Historically, price control and quantity rationing are widely used in wars and crises for managing social stability, while price deregulation exists in peaceful environments.

Transition experiments clearly demonstrate price instability during economic transitions. There are several factors in the price mechanism: network structure, product cycles, and adjustment speed in price dynamics.

2.5.1.1 Price structure and network effect

One claim in an efficient market hypothesis is that price contains all information (Fama 1970, 1991). The rational expectations school further believes that people will forecast price movements correctly by using market information efficiently (Lucas 1972, 1981). However, we observed a great variety of price inflation from transition countries (Table 2.4).

It was a well-known story of Ludwig Erhard, then Economic Minister in West Germany, who created a miracle in 1948, when the market prospered after price liberalization overnight from the ruin of World War II (Dornbusch 1993). Why did the price mechanism fail to make more magic in transition economies? The best case scenario for shock therapy was not Poland where there was "shock without therapy" but East Germany (Kolodko 2000; Chen 2006). West Germany offered a generous exchange ratio of a 1 (East German mark) to 1 (West German mark) exchange rate to East German residents, while the black market exchange rate was about 5~20 to 1. The monetary union induced high hopes of economic progress when it started in July 1990. Instead, East German output fell more than 50 percent from the 1989 level in just six months, and the unemployment rate rose from near zero to above 20 percent in many sectors. Several thousands of East German firms closed. East Germany received the largest financial aid in history from West Germany, which was about 65 percent of East Germany's real

Table 2.4 Peak inflation rate during the transition (measured by the implicit price deflator in national currency)

Country	*Peak inflation (%) (year)*	*Length of high inflation (>40%)*
China	13 (1988), 20 (1994)	0
East Germany	9 (1990)	0
Poland	400–581 (1989–1990)	5 years (1988–1992)
Bulgaria	334–1068 (1991–1997)	7 years (1991–1997)
Romania	295–300 (1991–1992)	9 years (1991–2000)
Ukraine	3432 (1993)	6 years (1991–1996)
Russia	1590–4079 (1992–1993)	8 years (1991–1998)

Source: United Nations Statistics Database.

GDP from 1991 to 1998 (von Hagen and Strauch 2001). In comparison, the Marshall Plan to West Germany after World War II was much less than 5 percent of its national income. The East German population declined 10 percent in five years.

The causes of East Germany's decline were quite simple. First, German monetary union broke the traditional trade networks of East Germany with CMEA (Council for Mutual Economic Assistance) countries that had little hard currencies for trade. Second, trade liberalization gave little space for East German firms in adapting new market environment, so that East German firms lost both international and domestic market at the same time. Third, East German workers lost their competitiveness when German unions demanded premature wage convergence ahead of productivity growth. In short, East German industries suffered tremendous loss after monetary union and trade liberalization.

The negative impact of price and trade liberalization was more severe in the former Soviet Union than in East Europe, since the network effect was more significant for vertical integrated industries in the former Soviet Union.

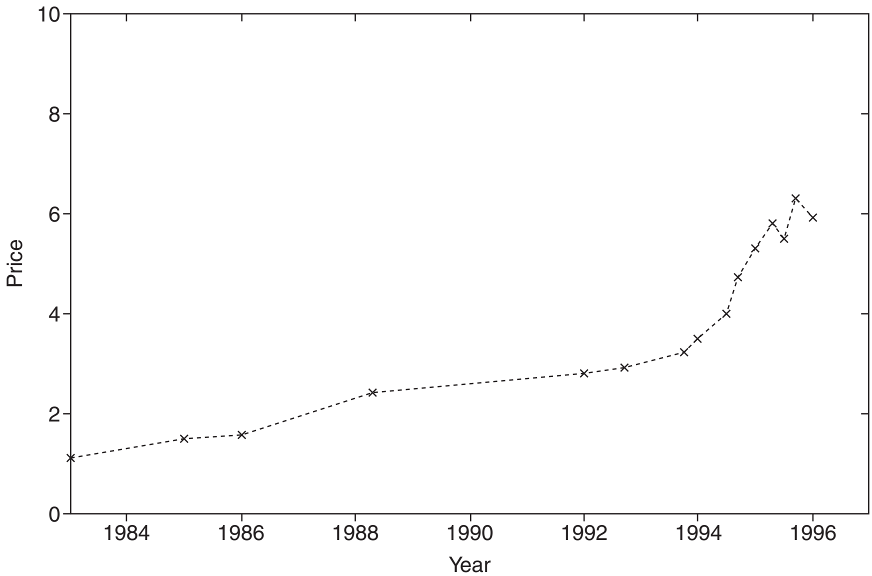
2.5.1.2 Product cycle and adjustment speed

Transition experiments also provided important information on adjustment speed in price fluctuations.

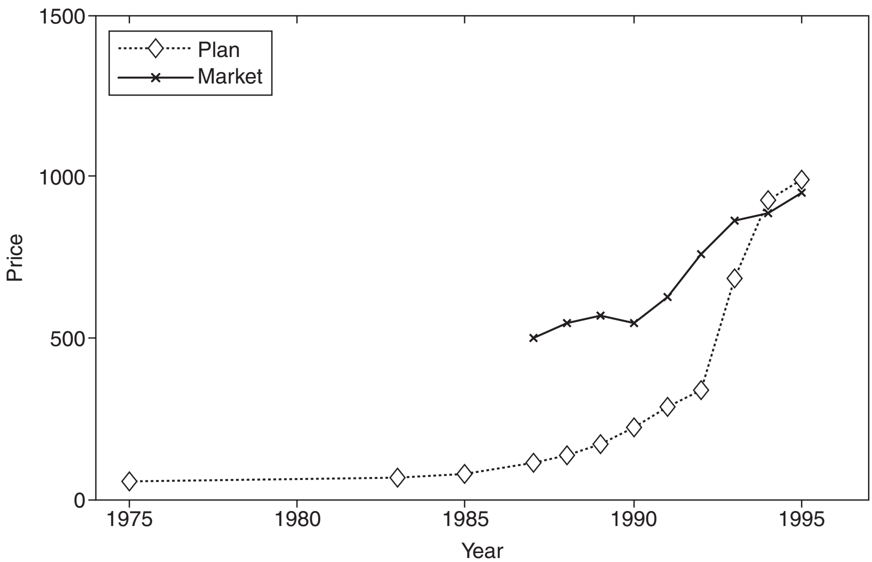
Diversified patterns were observed during China's dual-track price reform. The most rapid price convergence and output growth was achieved in the market for farm products such as meat and vegetables. Foodstuff prices did increase initially; but several months later, the prices quickly stabilized or even fell after a rapid growth in farm supply. For basic goods such as grain and cotton, price controls were on and off for more than ten years and never fully liberalized. The prices of industrial products were rapidly liberalized and deflation for consumer goods and luxury products occurred under intensifying competition. However, market liberalization for public goods was much slower. The prices for energy, utility, education, and health are still under tight control despite a persistent trend of price inflation, since their supply falls far behind social demand when income grows rapidly (see Figure 2.11).

These differences can be easily understood by differences in lengths of product and investment cycles: agricultural product cycles are typically several months, industry investment cycles vary from months to years. Building education and infrastructure may last decades.

From these observations, we could say the Arrow–Debreu model is more relevant to traditional agriculture than industrial economy. Product cycles and price complexity can be understood from roundabout production in division of labor (Hayek 1935).



(a)



(b)

Figure 2.11 Price history in China's Shanghai local market. (a) Fresh pork price in the retail market (1983–1995) (RMB/500g). (b) Heavy oil dual-track price in the industrial market (1975–1995) (RMB/1000 ton).

2.5.2 Macrofoundation of micro behavior and soft-budget constraints in financial market

The causal relation between micro and macro is an open issue in economics. There are three implications from microfoundations theory for macro and development policy. First, equilibrium pricing is the best mechanism for efficiency and growth. Second, privatization is a precondition of market oriented reform. Third, cutting government assistance to firms may improve SOE efficiency under the doctrine of so-called hard-budget constraints. These assumptions are essential in promoting liberalization, privatization, and stabilization programs. We will see that these policies are directly responsible for economic declines in EEFSU.

2.5.2.1 Equilibrium pricing vs. disequilibrium growth in transition strategies

The striking difference in reform policy is revealed from equilibrium and disequilibrium strategy in price mechanism and growth dynamics. Both China and EEFSU started their economic reform and transition from shortage economies. Clearly, you have two possibilities to eliminate shortage: you may increase supply with a disequilibrium policy for growth, or you may reduce demand with an equilibrium policy for the reallocation of resources.

From Chinese historical experience, shortage results from insufficient supply constrained by resource and productivity. Therefore, China's economic reform started with technology imports in the industrial sector and an incentive mechanism (in the form of a family contract system) in the rural sector. High economic growth was achieved under a slowly converging dual-track price system for three decades. As result, China has improved people's living standard and increasing savings and investment rapidly.

In contrast, price liberalization under shock therapy created tremendous inflation and currency devaluation that simply wiped out people's savings under the socialist system. High unemployment and increasing poverty emerged during the transition depression in EEFSU.

Shock therapists argued that price equilibrium improves economic efficiency by reducing waiting time under a shortage economy. This argument raises a fundamental question about the social meaning of economic efficiency. Neoclassical economics implicitly assumes that price equilibrium in micro is associated with growth in macro. This assumption is not true from the transition process (Figure 2.12).

We can see that China's average growth rate was much higher than Poland's (the best case in EEFSU) while China's inflation rate was much lower and more stable than Poland's. These facts told the simple story that disequilibrium growth strategy under stable macrofoundations was socially more desirable than equilibrium laissez-faire policy under unstable microfoundations.

A more visible case is the rapid expansion of China's export and technology advancement. Let us study the magnitude of currency devaluation during transition in Table 2.5.

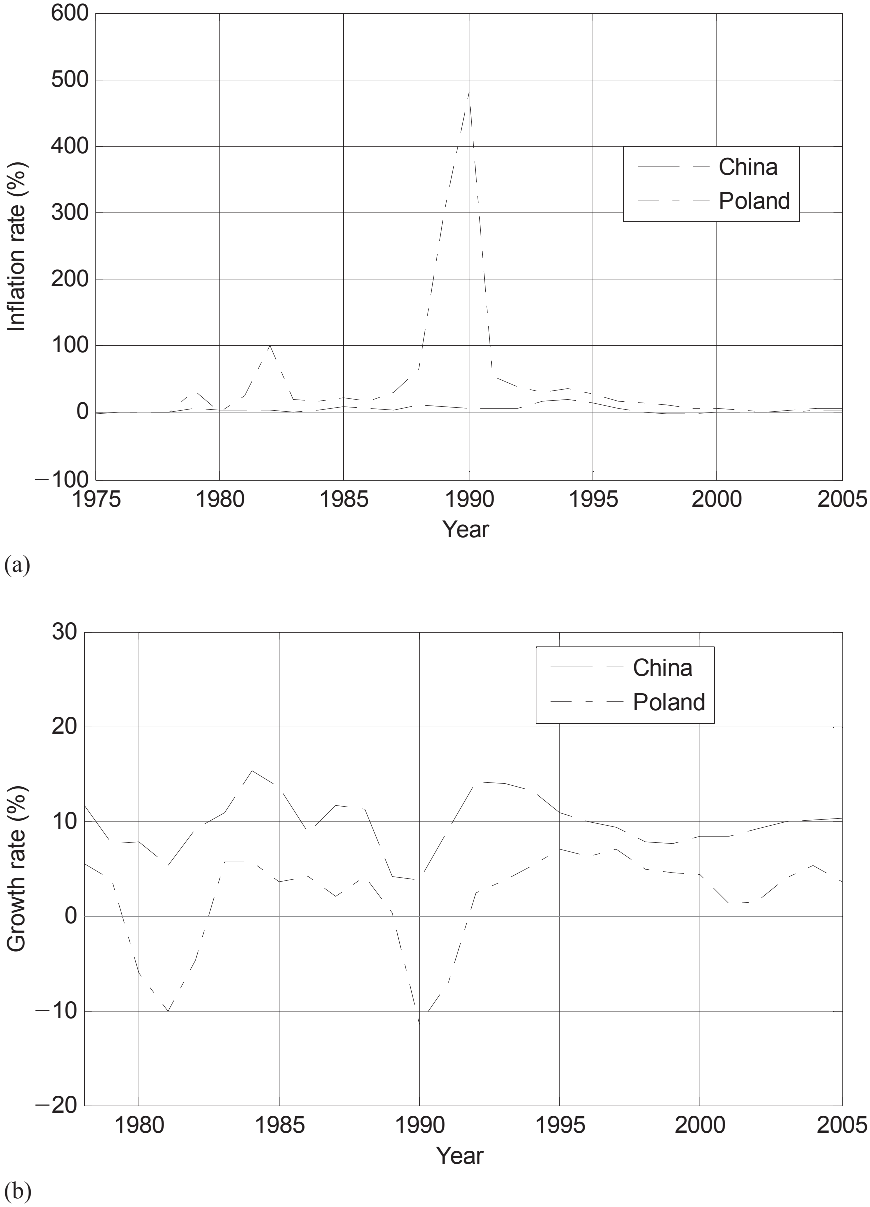


Figure 2.12 Macro stability and growth in China and Poland during transition (source: United Nations Statistics). (a) Inflation rate. (b) Real growth rate.

Table 2.5 Devaluation of currency (exchange rate set at 1980 or 1991)

Year	*1980*	*1985*	*1990*	*1991*	*1993*	*1995*	*2000*
China	1	1.96	3.19	3.55	3.85	5.57	5.52
Germany	1	1.62	0.89	0.91	0.91	0.79	1.17
Czech			0.77	1	1.04	0.95	1.38
Slovakia			0.61	1	1.04	1.01	1.56
Hungary	0.44	0.67	0.85	1	1.23	1.68	3.78
Poland		0.01	0.90	1	1.71	2.29	4.11
Bulgaria				1	1.55	3.78	0.12
Romania	0.22	0.24	0.29	1	9.95	26.62	284
Belarus			0.51	1	191	47,937	108
Russia				1	195	897	5534
Ukraine			0.50	1	634	20,602	76,087

Source: Penn World Table 2002.

Note
The exchange rates are measured against the dollar. All exchange rates are re-scaled by the base year, which are 1980 for Germany and China and 1991 for the rest.

It seems that tremendous currency devaluation in Romania and the former Soviet Union was caused by political instability. The lost value of effective government can be seen from the sheer magnitude of currency devaluation in the former Soviet Union. For example, from 1990 to 1998, real GDP measured by the 1990 US dollar declined 43 percent for Russia and 61 percent for Ukraine, but their currency depreciated 5534 and 76,087 times respectively! This discrepancy cannot be explained by market forces without macro management by government.

Both China and Central European countries such as the Czech Republic and Poland maintained currency stability with two differences: China managed its currency stability by managing foreign trade and controlling capital accounts without large scale foreign assistance; China also rapidly turned from trade deficits into trade surplus as shown in Figure 2.13.

The interaction between macro growth and micro adjustment can be seen from the slow price convergence in the foreign currency market. China's dual exchange rate system lasted 15 years, which started in 1980 when the trade deficit was $1.8 billion and ended in 1995 when the trade surplus reached $5.4 billion in 1994. China's foreign reserves also increased from $800 million in 1979 to $51.6 billion in 1994 and more than $1.6 trillion in 2008. Within this period, China's export growth rate was 26 percent, more than double the real GDP growth rate of 9.5 percent. As observed by a leading Polish economist, "the more rapid the liberalization of trade, the bigger the initial shock and the deeper the ensuing recession" (Kolodko 2000).

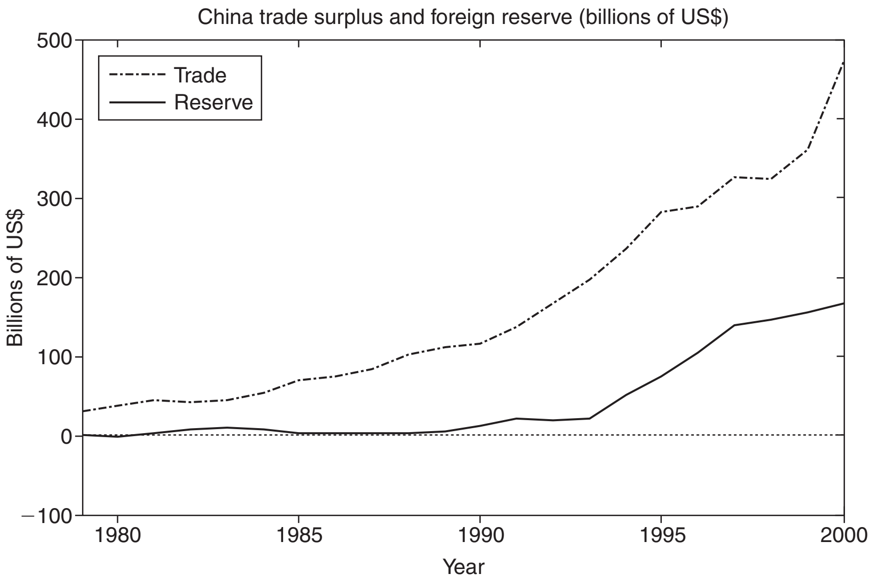


Figure 2.13 China's trade surplus and foreign reserves (source: China Statistics 2001).

2.5.2.2 Hard-budget constraints for firms and the credit crunch during recession

One influential theory in transition economics is that of so-called soft-budget constraints by the Hungarian economist Kornai, who wrongly blamed the state subsidy as the cause of the inefficiency of state firms (Kornai 1979, 1986). The logic of the hard-budget constraints is true only for a closed economy but not true for an open economy with innovation competition. In industrial societies, soft-budget constraints widely exist in various forms, including bank credit, venture capital, and bankruptcy laws. The Long-Term Capital and rescue effort in the recent sub-prime loan crisis are well-known example of soft-budget constraints in the US. In practice, the credit crunch by imposing "hard budget-constraints" is an additional cause of the output decline in EEFSU (Calvo and Coricelli 1992).

China's rapid economic growth during transition made a good example of growth under soft (but creative) budget constraints (Chen 2005). When open-door policies introduce international competition to domestic firms, the critical choice is how to upgrade technology for a domestic firm's survival. Access to bank credit and capital market is crucial to a firm's survival in a globally competitive market. China's rapid technology progress was benefited by state insurance during a learning process. A farmer's down-side risk is protected by collective ownership of land. China's public workers were encouraged by state policy, which preserved positions for those in business adventures. Whether China's growth under soft-budget constraints can be continued, the answer does not depend on the cost of soft-budget constraints, but the productivity gain over the social cost. China's growth oriented development strategy is a new type of Keynesian policy for encouraging innovation, while the Kornai policy of hard-budget constraints in the name of stabilizing program was simply a new form of counter-Keynesian revolution.

Theoretically speaking, the theory of soft-budget constraints is a naïve exercise in microeconomics, but a dubious theory in macroeconomics. If the survival of large numbers of socialist firms only depends on state subsidies, socialist countries would have much higher inflation than market economies; this is not true historically. Persistent budget deficits and hyper inflation rarely occurred in planned economies but frequently occurred in market economies such as in Latin America. Kornai made a misleading diagnosis of the planned economy. As Schumpeter pointed out, capitalism is driven by innovation, which is intrinsically unstable. Socialism is more stable in a closed society. The main weakness of planned economies is not economic inefficiency but stagnation of technology resulting from the closed-door policy in the Stalin era.

2.5.3 Structure of mixed economies and essence of institutional changes

Two ideas behind privatization policy: private ownership was the optimal form and a private property rights system is a precondition for a successful market economy. The rise of the Chinese economy under mixed property rights sheds new light on the proper structure of mixed economies and basic lessons in institutional changes. New institutional economics based on Coase theory and the property rights school has one implicit implication: the Anglo-Saxon system of a capitalist economy is the optimal institution, so that world development should converge to this system regardless of ecological and historical conditions. We will see this belief is challenged by transition experiments.

2.5.3.1 Trade-offs between private and non-private economies

Samuelson pointed out that the essence of a market economy is a mixed economy (Samuelson 1961). However, after the fall of the Berlin Wall in 1989, there was a wide belief that the collapse of the Soviet Union signaled the superiority of private ownership. The success of China's economic transition stimulated us to have a second look at historical facts (see Table 2.6).

There is no empirical evidence that a socialist economy is less efficient than a capitalist economy. Yes, the US did best in 1913–1950 and Japan did best in 1950–1973 under favorable international conditions. Socialist economies performed above average in 1950–1973 and China did best in 1970–2001. It was more likely that political rather than economic causes led to the collapse of the former Soviet Union.

Table 2.6 World economy, historical statistics (annual average compound rate of GDP growth)

Period	*WEuro*	*EEuro*	*Asia*	*US*	*Japan*	*fUSSR*	*China*
1913–1950	1.19	0.86	0.82	2.84	2.21	2.15	–0.02
1950–1973	4.79	4.86	5.17	3.93	9.29	4.84	5.02
1973–2001	2.21	1.01	5.41	2.94	2.71	–0.42	6.72

Source: Maddison (2007).

Note
Asia data excluded Japan.

From the view of the property rights school, both SOEs and TVEs have no clearly defined property rights. In financial practice, shares of local governments could enhance a firm's credit for a bank loan. Certainly, growth under soft-budget constraints does have costs in the form of non-performing loans (NPL) accumulated in state banks. China's growth under soft-budget constraints creates a trial and wins through informal privatization: if SOEs or TVEs succeed in new product markets, you privatize it; when you fail, the state-owned banks absorb a large financial cost. In this way, China's state sector took the main cost in technology learning and business ventures generated in the non-state sector. The NPL contains both components of efficiency loss and social burden. The recent estimation of China's NPL of state banks was about 2.1 trillion RMB or $300 billion dollars. After restructuring and IPO (Initial Public Offering), China's state banks created more social value above the cost, which was about one trillion RMB or $140 billion (*New Beijing News* 2008). In contrast, East German industry had much better technology and human resources than China in its initial condition. Before German unification in 1990, total asset value of East German SOEs was estimated in the range of several hundred billion DM. After rapid privatization under Treuhand, a state agency directed by West German officials, the total loss was $200 billion in five years (Stack 1997).

China's booming economy is characterized by strong competition among all types of ownership structures, including private, collective, state, foreign, and joint-stock firms. Even in advanced technology such as the automobile industry, more than a dozen newly emerged private and local state companies are successfully competing with multi-national companies in domestic and international markets.

One important lesson from transition is the priority between competition policy and privatization policy. China greatly improved competitiveness and efficiency by breaking the state monopoly into competing state firms before transforming them into joint-stock companies. Notable examples are China Airlines and the China People's Bank, which were broken up into several competing firms. But many of Russia's giant state monopoly firms came to be owned by private oligarchs after privatization. As a result, China attracts more foreign direct investments because China's market is more open and competitive than EEFSU.

The Washington consensus did compile a large to-do list including public investment in health care, education, and infrastructure but failed to consider how to finance them in developing countries (Williamson 1990). Sachs complained that insufficient aid was the ultimate cause of poverty and failure of shock therapy (Sachs 2005). China's innovation in public financing is selling user right while preserving public ownership of land, which creates increasing public assets during economic growth. American strength in R&D is based on its land-grant state universities. By the same token, China's labor is not cheap if you count the tremendous training cost in transforming farm youths into skilled workers and technicians. China's competitiveness in the global market is a low-cost social security system based on collective ownership of land for farmers and infrastructure investment financed by state-owned land rent in cities (Chen 2006). Wholesale privatization in EEFSU not only created a large scale of unemployment and poverty, but also shrunk state ability in maintaining macro stability and public investment.

2.5.3.2 The driving force of institutional changes: top-down design vs. decentralized experiments

The logic of rapid privatization was political rather than economic. Market fundamentalists argued that creating a capitalist class was a precondition to establish market institution (Shleifer and Treisman 2005). Unfortunately, creating oligarchs as well as mass poverty induced more public enemies than political supporters in economic transition. China's market oriented reform won more public support than EEFSU simply because the majority of China's people rapidly improved their living standard while EEFSU suffered significant decline in living standard and even life expectancy.

One visible dilemma is the top-down design approach by market fundamentalists who claim a belief in decentralized competition; while China's decentralized experiment in economic reform was conducted under a centralized government. The main difference is: market fundamentalists believe they have perfect knowledge on optimal-universal market institutions, but Chinese leaders realized that they knew little about a working market model under China's historical constraints. The real issue in transition economics is not reform speed and sequence as in the debate between shock therapy and gradualism. The central issue is about the nature or driving force of institutional changes.

Two examples show the nature of institutional changes. One big mistake for East German worker unions was the premature demand for a wage standard close to West German workers before increasing their productivity. The outcome was loss of their competitiveness to East European workers. Another problem is German regulation pro existing giant firms but discouraging innovation from small firms. This is an important reason that German industry fell behind American and Japan in newly developed industries such as the Internet and digital equipment. China's new industries rapidly emerged in SEZ (Special Economic Zone) simply because they are not bounded by obsolete regulation and are supported by innovative local governments. There is no equal and fair competition under complex regulation in division of labor. The issue is the asymmetric nature of the selection mechanism. China's priority is pro innovation for job creation and technology advancement, while the Washington consensus looks like pro law and order. In fact, multi-national companies are the real winners of liberalization and privatization in EEFSU, even at long-term costs for the Western world as a whole.

The tremendous costs of Transition Depression stimulated another way of thinking: social evolution is more like biological evolution, which is a divergent process characterized by bifurcation trees. There is no universal model in a market system. In addition to the Anglo-Saxon model, we already witness the emergence of a Germany–Japan model, a Scandinavia model (Hall and Soskice 2001), and perhaps a China model in the near future.

2.6 Evolutionary perspective as a better alternative in theoretical foundation of economics

From the above discussion, we can clearly see that simple models in equilibrium economics are not capable of characterizing the main features of a market economy, such as persistent cycles and creative destruction. The equilibrium illusion of market equilibrium and institutional convergence was created by linear models and representative agents without nonlinear interaction and collective behavior. The main pillars of equilibrium beliefs, such as the Frisch model of noise-driven cycles, the Lucas model of microfoundations, and the Coasian world of zero-transaction costs are equilibrium illusions that violate basic laws in biophysics and mathematics.

There was a wrong perception that evolutionary economics is not scientific since it mainly counts on historical interpretation and philosophical arguments. Now, we can see that the advancement of nonlinear dynamics and complexity science provides powerful tools not only in empirical analysis but also theoretical modeling. Here, we propose a preliminary outline for further development.

2.6.1 Biophysical foundation and mathematical framework

Economic systems are dissipative systems in nature. An optimization approach based on a Hamiltonian framework should shift to evolutionary dynamics with nonlinear resources and market constraints. Asymmetric preference in micro behavior, social interaction in financial markets, persistent cycles and fluctuations in macro, and path-dependence in historical evolution are nonlinear phenomena that must be considered in theoretical analysis. Oversimplifying concepts in equilibrium economics, such as unlimited want in utility function, perfect information, zero-transaction costs, perfect markets, perfect foresight, or rational expectations, should be analyzed and eventually abandoned in textbook economics, since they are not only impossible for finite life with finite resources or finite ability to process information, but also dangerous as policy guidance.

Existing anomalies in equilibrium theory, such as scale economy, collective behavior, persistent unemployment, large fluctuations, and economic crisis, can be better understood by economic complexity with ecological constraints and social interactions.

In mathematical economics and econometric analysis, new analytical tools should be introduced to economics students, including nonlinear nonstationary time series analysis in frequency domain, nonlinear dynamics, wavelets, statistical mechanics, and network models. Continuous-time models and differential equations are better than discrete-time models and algebra equations in dynamic modeling. Economic thinking in mathematics faces a revolutionary transition from the pre-Newtonian era (in the sense of discrete time) and low-dimensional Euclidean geometry, such as Edgeworth box and linear demand–supply curves, to complexity science, including nonlinear dynamics, high-dimensional non-Euclidean space, network, and new algorithms in signal processing.

In empirical analysis, there is no such thing as perfect information. The critical issue is asking pertinent questions and designing proper filters to select relevant information, so that a better dialogue between theoretical modeling and empirical observation can be fruitful in decision making. The better analytical base function for time series analysis is the logistic wavelet rather than the noisy pulse.

For academic economists, a fundamental shift in theoretical tastes is essential for advancement of economic science. In the era of complexity science, we have a rare chance to find an analytical solution for nonlinear systems. Computer simulation and graphic representation will play an increasing role in theoretical and empirical analysis. Economic study cannot be simply judged by mathematical simplicity or logical beauty without empirical support and theoretical relevance. Many policy discussions in textbook economics are based on the concept of so-called market distortion by regulation, which is operating in an economic vacuum without ecological constraints, macro fluctuations, international competition, and social interactions. A better approach is studying market interactions with both positive and negative feedback loops, which are familiar in system dynamics but rarely used in atomic economics.

2.6.2 Three levels of economic structure: micro–meso–macro in economic organism

The microfoundations approach, a two-level micro–macro model, is not capable of understanding large and persistent business cycles and financial crisis. A three-level model of micro–meso (financial intermediate and industrial organization)–macro is a better framework for policy analysis.

A critical issue is proper time scale in economic analysis. Currently, the time scale in micro analysis is static; financial analysis ranges from an extremely short time window such as seconds in econophysics to several decades in corporate finance; macro analysis mainly studies the range of business cycles from about two to ten years to a so-called long-run equilibrium of 100 years. In our framework, macro research should extend the time scale from business cycles to ecological cycles from decades to 1000 years, which is necessary to study interactions between population, resources, technology, culture, and economic policy. Micro and meso research should focus on business cycle periods for studying micro behavior under business cycles and financial constraints. The most difficult is the meso level. Financial economics cannot be confined within a closed economy. Interactions among trends, cycles, and fluctuations are needed in understanding alternative value creation and bubble collapse in boom and bust cycles.

2.6.3 Unsolved problems in theory and policy

The best way to advance empirical science is addressing unsolved problems, which are fundamental for the next generation of economists. New questions may open a new field for economic study.

2.6.3.1 Population dynamics with resource constraints and culture factors

The question of why some countries are rich and some poor is a naïve question within a short historical perspective. A more fundamental question is how to build a sustainable economy with peace and prosperity. Wealth is a function of resources, technology, and population. Currently, developed countries have a high living standard but an aging and even shrinking population; while developing countries have young and growing populations with diminishing job opportunities. This situation cannot be sustained even if modern technology is capable of feeding the world population or destroying the entire earth many times.

Many factors may have a profound impact on population dynamics: culture orientation, resource limitation, women education, health care system, economic incentive, income distribution, welfare system, world trade, and immigration. The difficulty is: this is a global problem which cannot be solved by national policy. Failure in international coordination in population policy may increase conflicts, crisis, and war under the intensive pressure of an environmental crisis.

2.6.3.2 Trend–cycle separation in growth dynamics and scenario analysis in production, distribution, and development

Microeconomics is started with resource allocation under perfect competition. Economic efficiency is represented as static equilibrium under a fixed market price. The static concept of market efficiency cannot be distinguished from the equilibrium trap in underdevelopment with numerous primitive producers without scale economy in division of labor. The concept of Pareto efficiency simply denies the needs of social reform when poverty results from a large disparity in wealth distribution.

Both in developing and developed countries, an important question in macro policy and institutional arrangement is studying trend–cycle relations in macro dynamics. New classical macroeconomics considers all types of cycles are waste, while Schumpeter realized the positive aspect of creative destruction. Keynesian economics mainly concerns stabilization policy while development and supply-side economics pays more attention to growth. The real issue is trade-offs between growth trends and cyclic instability under ecological and historical constraints. Prescott reinvented the HP filter, which separates a nonlinear smooth trend with cycles in two to ten years (Hodrick and Prescott 1997). Schumpeter identified three different cycles. Further decomposition business cycles with sector analysis may reveal deep structure changes driven by technology wavelets, which may shed more light on development policy based on technology metabolism (Chen 2005).

2.6.3.3 Pricing strategies and price-expectation dynamics

The textbook micro theory of marginal pricing is rarely observed in economic activity. Cost plus pricing is widely used under financial constraints. Strategic pricing has many varieties for increasing market share, establishing entry barriers, or brand building. Interaction between image shaping and price trend is critical in price-expectation dynamics, which is observed in an IPO in financial markets.

2.6.3.4 Origin of the coordinated hand and disciplined hand

In contemporary industrial society, the invisible hand rarely functions even in developed countries. The real issue is how to deal with market failure and government failure under economic complexity. The more relevant question is the origin of the coordinated hand for market and disciplined hand for government, including culture norms, regulation mechanisms, and their trade-offs. A culture norm may develop mutual trust and cooperative behavior or discourage innovation or competition. Regulation needs a careful balance in promoting stability and innovation. Multi-factor analysis in a short- and long-time perspective is needed in institutional study, mechanism design, and experiment. Coordination and interactions among market, government, and civil society may be a better mechanism than antagonism between market and government or checks and balances among competing interest groups. Evolutionary dynamics with asymmetric constraints and asymmetric behavior may provide a better alternative than game theory based on symmetric rule and symmetric information.

2.6.3.5 Rethinking human nature and economic wellbeing

The human is a social animal with limited material wants and unlimited intellectual capability because human activity is subject to the biological constraints of finite life but an essentially infinite combination of human characters. The real challenge for economics is to define a sustainable system in ecology and choice range for the welfare of the majority of people, not just a few. Current technology is capable of feeding the world population, but current incentive mechanisms and rules of the game cannot maintain peace and prosperity. A new trinity is needed for a proper balance among private, government, society, including NPO (non-profit organization) and NGO (non-government organization) in a mixed economy, and a new international order for rich and poor countries. We cannot promote free trade but not flexible immigration at the same time. For developing a diversified global economy, a more realistic issue is developing an open global economy with diversified culture and economic systems, where varying types of regulation in trade, capital, immigration, and welfare systems may compete and co-evolve in a more constructive way.

Western civilization made great contributions in developing science and technology. However, it also created tremendous uncertainty regarding ecological and cultural systems. A new dialogue and experiments among different civilizations is needed for a new economy and a new science of complexity.

2.7 Conclusion

Neo-classical economics laid down the starting base in mathematical economics and econometric analysis, which are useful in explaining simple phenomena in a short time window but limited as policy guidance or strategic choice. Lessons from the Transition Depression told us that equilibrium thinking created idealized illusions for free trade and laissez-faire government but few solutions in dealing with market instability and social problems. A new science of complexity will devote more effort for studying nonlinear dynamics and nonequilibrium mechanisms, which are new tools for better understanding economic development and social evolution.

Acknowledgment

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6 A random walk or color chaos on the stock market?

Time–frequency analysis of S&P indexes[1]

6.1 Introduction

Finance theory in equilibrium economics is based on the random-walk model of stock prices. However, there is a more general scenario: a mixed process with random noise and deterministic pattern, including a possibility of deterministic chaos.

Chaos is widely found in the fields of physics, chemistry, and biology. But the existence of economic chaos is still an open issue (Barnett and Chen 1988; Brock and Sayers 1988; Ramsey *et al.* 1990; DeCoster and Mitchell 1991, 1992; Barnett *et al.* 1997). Trends, noise, and time evolution caused by structural changes are the main difficulties in economic time series analysis. A more generalized spectral analysis is needed for testing economic chaos (Chen 1988a, 1993a).

Measurement cannot be separated from theory. There are two polar models in linear dynamics: white noise and harmonic cycle. Correlation analysis and spectral analysis are complementary tools in the stationary time series analysis. White noise has a zero correlation and a flat spectrum while a harmonic cycle has an infinite correlation and a sharp line with zero width. Obviously, real data fall between these two extremes.

A major challenge in economic time series analysis is how to deal with time evolution. Econometric models, such as the ARCH and GARCH models with a changing mean and variance are parametric models in the nonstationary stochastic approach (Engle 1982; Bollerslev 1986). A generalized spectral approach is more useful in studies of deterministic chaos (Chen 1993a).

It is known that a stationary stochastic process does not have a stationary or continuous instantaneous frequency in time–frequency representation. Therefore, we do not use the terms stationary and nonstationary which are familiar in a stochastic approach. A new representation will introduce some conceptual changes. There are many fundamental differences between a nonlinear deterministic approach and a linear stochastic approach including time scales, observation references, and testing methodology.

From the view of theoretical studies, the discrete-time white chaos generated by nonlinear difference equations is tractable in analytic mathematics and compatible with the optimization rationality (Day and Benhabib 1981; Benhabib

1992). From the needs of empirical analysis, the continuous-time color chaos generated by nonlinear differential equations is more capable of describing observed business cycles than white chaos, because their erratic fluctuations and recurrent pattern can be characterized by nonlinear oscillations with irregular amplitude and a narrow frequency (color) band in spectrum (Chen 1988a, 1993a; Zarnowitz 1992).

We introduce the time–frequency representation as a non-parametric approach of generalized spectral analysis for the evolutionary time series (Qian and Chen 1996). The Wigner distribution in quantum mechanics and the Gabor representation in communication theory were pioneered by two Nobel laureate physicists (Wigner 1932; Gabor 1946). Applied scientists in signal processing have made fundamental progress in developing efficient algorithms of time–frequency distribution series (Qian and Chen 1993, 1994, 1996). These are powerful tools in our studies of economic chaos (Chen 1994, 1995).

In dealing with problems of growing trends and strong noise, we apply the Hodrick–Prescott (HP) filter for trend–cycle decomposition (Hodrick and Prescott 1997) and time-variant filters in Gabor space for pattern recognition (Qian and Chen 1996; Sun *et al.* 1996). We got clear signals of low-dimensional color chaos from Standard & Poor stock market indicators. The chaos signals can explain about 70 percent of stock variances from detrended cycles. Its characteristic period is around three to four years. Their correlation dimension is about 2.5. The time paths of their characteristic period is useful in analyzing cause and effect from historical events. Clearly, the color-chaos model describes more features of market movements than the popular random-walk model.

The newly decoded deterministic signals from persistent business cycles reveal new sources of market uncertainty and develop new ways of economic diagnostics and risk analysis. Friedman's argument against irrational speculators ignores the issue of information ambiguity in evolving economy and financial risk for rational arbitrageurs (Friedman 1953b). A nonlinear pattern in the stock market may not be wiped out by market competition because complexity and diversity in market behavior are generated by changing uncertainty, nonlinear overshooting, and time delays in learning and feedback mechanism.

6.2 Roles of time scale and reference trend in representation of business cycles

A distinctive problem in economic analysis is how to deal with growing trends in an aggregate economic time series. Unlike laboratory experiments in natural sciences, there is no way to maintain steady flows in economic growth and describe raw business cycles by invariant attractors. Many controversial issues in macroeconomic studies, such as noise versus chaos in business cycles, are closely related to competing detrending methods (Chen 1988a, 1993a; Ramsey *et al.* 1990; Brock and Sayers 1988).

The first issue is the time scale in economic representation. A continuous-time representation in the form of $[X(t), dX(t)/dt, \ldots, d^nX(t)/dt^n n]$ is widely used in science and engineering. It is an empirical question whether the dynamical system can be well approximated by a low-order vector up to the n-th order of derivatives. In Hamiltonian mechanics, n is 1 for mechanical systems because its future movement can be determined by the Newton's law of motion in addition to initial conditions in position and momentum. It means that both level (position) and rate (velocity) information are important in characterizing the underlying dynamical system. Chaos theory in nonlinear dynamics further emphasizes the role of history because a nonlinear deterministic system is sensitive to its initial conditions. In business-cycle studies, there is no consensus on the order n. The martingale theory of the stock market simply ignores the path-dependent information in the stock market. We will demonstrate that both level and rate information are important when correlations are not short during business cycles.

Econometricians often use differences in the form of $[X(t), \Delta X(t), \ldots, A^m X(t)]$ in parametric modeling. We should note that these two representations are not equivalent. Mathematically, a one-dimensional differential equation

$$\frac{dX(t)}{dt} = F(X, t)$$

can be approximated by m-th order difference equations. Numerically, m should be larger than 100 when the numerical error is required to be less than 1 percent. Many econometricians favor the discrete-time difference equations instead of the continuous-time differential equations because of its mathematical convenience in regression analysis. However, a discrete-time representation is a two-order lower approximation of a similar continuous-time system.

The issue of choosing an appropriate time-sampling rate is often ignored in econometric analysis. Chaotic cycles in continuous time may look like random if the sampling time interval is not small compared to its fundamental period of the cycles. This issue is important in pattern recognition. For example, annual economic data are not capable of revealing the frequency pattern of business cycles. Numerically, a large time unit such as the annual time series can easily obscure a cyclic pattern in correlation analysis of business cycles.

A related issue is how to choose a reference trend or a proper transformation to simplify the empirical pattern of business cycles. Suppose, a new vector [G(t), C(t)] is defined in terms of the original vector [X(t), dX(t)/dt]. If C(t) is a bounded time series, then C(t) has a chance to be described by a deterministic attractor, or a stationary stochastic process. In business-cycle studies, finding a proper transformation is called the problem of trend–cycle decomposition or simply detrending. In astronomy, the critical trend–cycle problem was solved by Copernicus and Kepler by using a heliocentric reference system. In econometrics, the choice of observation reference is an open issue in business-cycle theory (Zarnowitz 1992).

The core problem in economic analysis is not noise-smoothing but trend-defining in economic observation and decision making. A short-time deviation may be important for speculative arbitrageurs while the shape of the long-term trend can be critical to strategic investors. Certainly, investors in a real economy have diversified strategies and time horizons. The interactive nature of social behavior often forms some consensus on business cycles. This fact suggests that a relative preferred reference exists in economic studies. We will show that the HP filter in trend–cycle decomposition is a promising way to define a smooth growth trend in business cycles.

It is the theoretical perspective which dictates the choice of a detrending approach. Econometric practice of pre-whitening data is justified by equilibrium theory and convenient for regression analysis. For example, a Frisch-type noise-driven model of business cycles will end with white noise after several damped oscillations (Frisch 1933). For pattern recognition, a typical technique in science and engineering is to project the data on some well-constructed deterministic space to recover possible patterns from empirical time series. Notable examples are the Fourier analysis and wavelets.

There are two criteria in choosing the proper mathematical representation: mathematical reliability and empirical verifiability. Unlike experimental economics, macroeconomic time series are not reproducible in history. Traditional tests in econometric analysis have limited power in studies of an evolutionary economy containing deterministic components. For example, testing the whiteness of residuals or comparing mean squared errors have little power when the real economy is not a stationary stochastic process. A good fit of past data does not guarantee the ability for better future predictions. The outcome of out of sample tests in a simulation experiment depends on the choice of testing period, because structural changes vary in economic history.

To avoid the above problems in time–frequency analysis, we will use historical events as natural experiments to test our approach. Future laboratory experiments are possible in testing the martingale model and the color-chaos model in market behavior.

6.3 Trend cycle decomposition and time window in observation

The linear detrending approach dominates econometric analysis because of its mathematical simplicity. There are two opposite approaches in econometric analysis: one is the trend-stationary (TS) approach using the log-linear detrending (LD), which implies the largest time window of the observed time series with a constant exponential growth trend. The other is the difference-stationary (DS) approach using the first differencing (FD), which implies the shortest time window of only one time unit with no trend but erratic fluctuations (Nelson and Plosser 1982).

$$X_{FD}(t) = \log S(t) - \log S(t-1) = \log\left[\frac{S(t)}{S(t-1)}\right]$$

$$X_{LLDc}(t) = \log S(t) - (a + bt)$$

A compromise between these two linear extreme approaches is the HP filter (Hodrick and Prescott 1997), which decomposes a nonstationary time series into a nonlinear smooth (slow varying) trend and a cyclic series around the trend, so that the average period of the cyclic series is in the range of NBER (National Bureau of Economic Research) business cycle about two to ten years with an average between four to five years. The HP smooth growth trend [G(t)] is obtained by minimizing the following function:

$$Min \sum [X(t)-G(t)]^2 + s \sum \{[G(t+1)-G(t)]-[G(t)-G(t-1)]\}^2$$

Here, s is the positive smoothing parameter in the HP filter, which penalizes variability in the growth component series.[2] For US annual data, s = 400 for annual data, 1600 for quarterly, and 14,400 for monthly series. The last parameter was suggested by Kydland. LL cycles of $X_{LLc}(t)$ are residuals from log-linear trend. LLg growth trend can be considered as the limiting case of the HPg growth trend when *s* goes to infinity for logarithmic data.

In principle, a choice of observation reference is associated with a theory of economic dynamics. Log-linear detrending implies a constant exponential growth which is the base case in the neo-classical exogenous growth theory (EXGT). The FD detrending produces a noisy picture that is predicted by the geometric random-walk model with a constant drift (or the so-called unit-root model in econometric literature). The efficient market hypothesis simply asserts that stock price movement is a martingale with short correlations in finance theory.

Economically speaking, the FD detrending in econometrics implies a mechanical system with only speed without care of its historical position. In other words, the level information in price indicators can be ignored in economic behavior. This assertion contradicts with economic practices, because traders constantly watch economic trends. Most economic contracts, including margin accounts in stock trading, are based on nominal terms. The error-correction model in econometrics tried to remedy the problem by adding some lagged-level information, such as using a one-year-before level as an approximation of the long-run equilibrium (Baba *et al.* 1992). Few will make an investment decision based only on the current rate of price changes.

Then comes the problem of what is the long-run equilibrium in the empirical sense. Option traders based on the Black–Scholes model find that it is extremely difficult to predict the mean, variance, and correlations from historical data (Merton 1990). A proper decomposition of trend and cycles may find an appropriate scheme to weigh short-term and long-run impact of economic movements in economic dynamics.

From the view of complex systems, the linear approach is not capable of describing complex patterns of business cycles (Day and Chen 1993). We need a better alternative of detrending. Statistically, a unit-root model can be better described by a nonlinear trend (Bierens 1997). The question is which nonlinear trend is proper for catching the pertinent feature of business-cycle mechanism.

We can only solve the issue by comparing empirical information revealed from competing approaches.

The essence of trend–cycle decomposition is to find an appropriate time window, or equivalently a proper frequency window, in observing nonstationary movements. From the view of signal processing, log-linear detrending is a low-pass filter or wave detector, first differencing is a high-pass filter or noise amplifier, while the HP filter is a band-pass filter. Obviously, the FD filter is hopeless for detecting low frequency cycles.

Early evidence of economic chaos is found in LL detrended data (Barnett and Chen 1988; Chen 1988a). The main drawback of LL detrending is its over-dependence of historical boundaries while the FD series is too erratic by amplifying high frequency noise (Friedman 1969b). The HP filter has two advantages. First, it is a localized approach in detrending with less dependence of arbitrary boundary choice. Second, its frequency response is in the range of NBER business cycles (King and Rebelo 1993). Some economists argue that the HP filter may transform a unit-root process into false cycles. A similar argument is also valid for the unit-root school, because the FD filter obscures complex cycles by amplifying random noise. No numerical experiment can solve a methodological issue. In the history of science, the choice of a proper reference can only be solved as an empirical issue, i.e., whether we can discover some patterns and regularities that are relevant to economic reality. We will see that introducing a time–frequency representation and the HP filter does reveal some historical features of business cycles, that are not observable through the FD filter.

In this chapter, we will demonstrate tests of two monthly time series from the stock market indicators: FSPCOM is the Standard & Poor's 500 stock price composite monthly index, and FSDXP, the S&P common stock composite dividend yield. The data covers a period from 1947 to 1992 in the Citibase. To save space, we only give the plots from the FSPCOM data. More tests in macroeconomic aggregates are reported elsewhere (Chen 1994, 1995, 1996b).

The role of detrending in shaping characteristic statistics can be seen in Table 6.1. For most economic time series, the magnitude of variance (a key parameter in asset pricing theory) and the length in autocorrelations (a key parameter in statistical tests) are closely associated with the characteristic time window of the underlying detrending method. The variance observed by HPc is about 5.7 times that of FDs, while the HPc decorrelation time T_d is 4.6 times of FDs. Their

Table 6.1 Detrending statistics for FSPCOM monthly

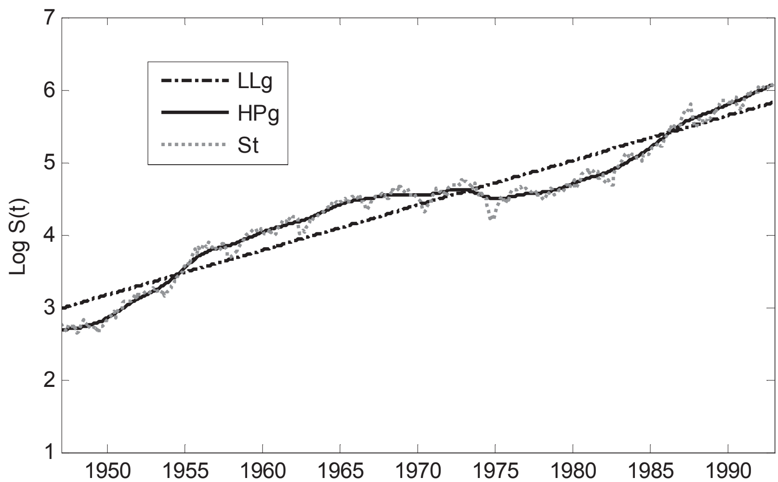
Detrending	*Mean*	*STD*	*Variance*	T_d *(month)*	P_{dc} *(year)*
FD	0.012	0.1123	0.0126	1.94	0.7
HP	0.008	0.2686	0.0722	8.93	3.0
LL	0.427	0.3265	0.1066	85.6	28.5

Notes

Here, T_d is the decorrelation time measured by the time lag of the first zero in autocorrelations; P_{dc}, the decorrelation period for implicit cycles: $P_{dc} = 4T_d$.

relative magnitude in variance is roughly in the same order as the ratio in the decorrelation time.

A typical example of an economic time series is shown in the logarithmic FSPCOM (see Figure 6.1). The contrast between the erratic feature of the FDs series and the wave-like feature of HPc and LLc cycles is striking. For example, their lengths of autocorrelations are greatly varied. The autocorrelation length is the largest for LLc cycles, shortest for FDs series, and in between for HPc cycles.



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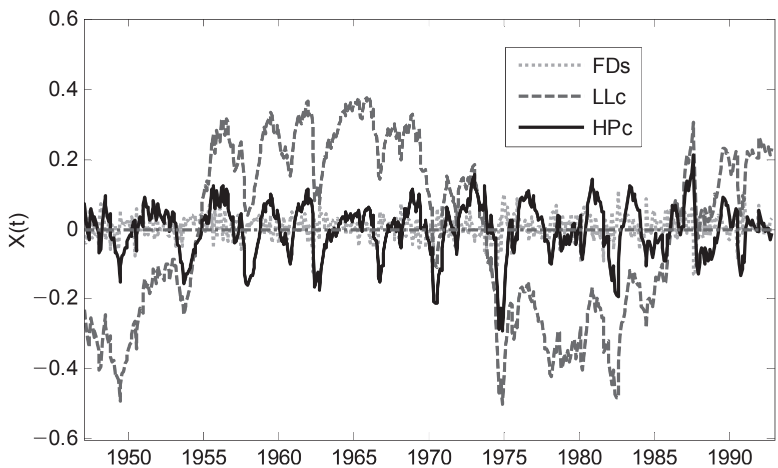

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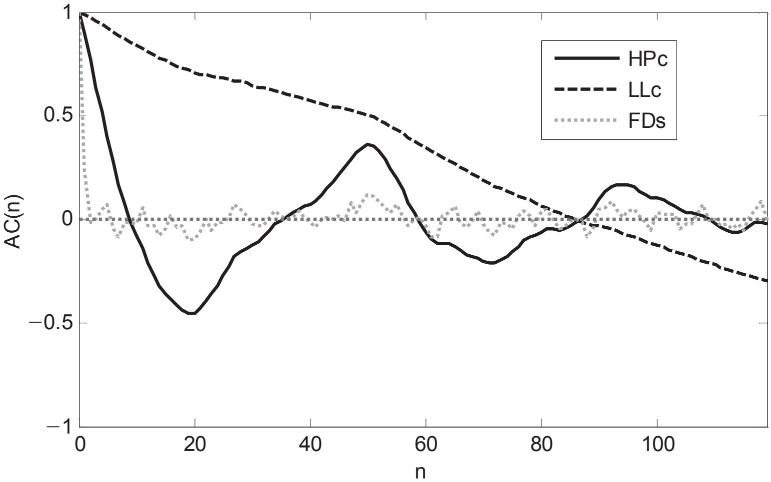
Figure 6.1 Fluctuation patterns from competing trend–cycle decompositions, including FD, HP, and LL (log-linear) detrending, for the logarithmic FSPCOM monthly series (1947–1992). (a) HPg and LLg growth trend. St is original series. (b) HPc, LLc, and FDs cyclic series. (c) Autocorrelations of HPc, LLc, and FDs. *contd.*



(c)

Figure 6.1 Continued.

6.4 Instantaneous autocorrelations and instantaneous frequency in time–frequency representation

In spectral representation, a plane wave has an infinite time span but a zero width in frequency domain. In a correlation representation, a pulse has a zero-width time span but a full window in frequency space. To overcome their shortcomings, the wavelet representation with a finite span both in time and frequency (or scale) can be constructed for an evolutionary time series. The simplest time–frequency distribution is the short-time Fourier transform (STFT) by imposing a shifting finite time window in the conventional Fourier spectrum.

The concepts of instantaneous autocorrelation and instantaneous frequency are important in developing generalized spectral analysis. A symmetric window in a localized time interval is introduced in the instantaneous autocorrelation function in the bilinear Wigner distribution (WD), the corresponding time-dependent frequency or simply time–frequency can be defined by the Fourier spectrum of its autocorrelations (Wigner 1932):

$$WD(t,\omega) = \int S\left(t+\frac{\tau}{2}\right)S^*\left(t-\frac{\tau}{2}\right)\exp(-i\,\omega\tau)\,d\tau$$

Continuous time–frequency representation can be approximated by a discretized two-dimensional time–frequency lattice. An important development in time–frequency analysis is the linear Gabor transform which maps the time series into the discretized two-dimensional time–frequency space (Gabor 1946).

According to the uncertainty principle in quantum mechanics and information theory, the minimum uncertainty only occurs for the Gaussian function.

$$\Delta t \ \Delta f \geq \frac{1}{4\pi}$$

where Δt measures the time uncertainty, Δf the frequency uncertainty (angular frequency: $\omega = 2\pi f$).

Gabor introduced the Gaussian window in non-orthogonal base function h(t).

$$S(t) = \sum_{m,n} C_{m,n} \ h_{m,n}(t)$$

$$h_{m,n}(t) = a * \exp\left[-\frac{(t - m\,\Delta t)^2}{(2L)^2}\right] * \exp(-i\,nt\,\Delta\omega)$$

where Δt is the sample time interval, $\Delta\omega$ is the sample frequency interval, L the normalized Gaussian window size, m and n the time and frequency coordinate in discretized time–frequency space (Qian and Chen 1994).

The discrete-time realization of the continuous-time Wigner distribution can be carried out by the orthogonal-like Gabor expansion in discrete time and frequency (Qian and Chen 1994, 1996).[3] The time–frequency distribution series (TFDS) can be constructed as the decomposed Wigner distribution.

$$TFDS_D(t, \omega) = \sum_{d=0}^{K} P_d(t, \omega)$$

where $P_d(t, \omega)$ is the d-th order of decomposed Wigner distribution, d is measured by the maximum distance between interacting pairs of base functions. The zero-th order of a time–frequency distribution series without interferences leads to STFT. The infinite order converges to the Wigner distribution including higher interference terms. For an applied analysis, second or third order is a good compromise in characterizing frequency representation without severe cross-term interference. In our studies, we take the highest order K = 3.

For comparison between the deterministic model and the stochastic model, we also demonstrate the time–frequency pattern of an AR(2) model of FDs.

$$X(t) = 0.006\,[0.002] + 0.265\,[0.043]X(t-1) - 0.081\,[0.043]X(t-2) + \xi(t)$$

Here, standard deviations are in parenthesis, the residual $\xi(t)$ is white noise, its standard deviation is: $\sigma = 0.033$.

The deterministic cycle is characterized by a narrow horizontal frequency band in time–frequency space, while noise signals featured by drop-like images are evenly scattered in whole time–frequency space. We can see that FD series are very noisy while HPc cycles have a clear trace of persistent cycles in the range of business-cycle frequency. Later we will show that a stationary stochastic model, such as an AR(2) model of FD series, has a typical feature of color noise without a continuous frequency line in time–frequency representation. A noise-driven model such as an AR or GARCH series can produce pseudo-cycles in Fourier spectrum, but cannot produce persistent cycles in time–frequency representation.

The time–frequency representations of the logarithmic FSPCOM HPc and FDs are shown in Figure 6.2.

For the deterministic mechanism, signal energy or variance is highly localized in time–frequency space. For example, the signal of FSPCOM HPc cycles are concentrated in the lowest quarter frequency zone. Its characteristic period P_c is 3.9 years; 89 percent of its variance is concentrated within a bandwidth of a 12 percent frequency window, 73 percent within a 5 percent frequency window. Clearly, the FD perspective simply misses the larger picture in time–frequency space.

6.5 Time variant filter in Gabor space

The task of removing background noise is quite different in the trajectory representation and in time–frequency representation. It is very difficult to judge a good regression simply based on a residual test in econometrics. It is much easier to examine the linear Gabor distribution in the time–frequency space. We want to find a simple way to extract the main area with a high energy concentration, which can be reconstructed into a time series resembling main features of the original data. We will see if the filtered time series can be described by a simple deterministic oscillator.

For a stationary stochastic process, a linear filter can be applied. For an evolutionary process containing both deterministic and stochastic components, a time-variant nonlinear filter does a better job. The simplest time-variant filter is a mask function that marks the boundaries of the energy concentration area.

It is much easier to construct a time-variant filter based on the Gabor transform than on the Wigner transform, because the Gabor transform is linear. The original time series $X_o(t)$ can be represented by a M*N matrix in Gabor space. Its element C(m, n) has M points in the time frame and N points in the frequency frame. There is no absolute dividing line between cycles and noise in Gabor representation. We can define the thresholds of a peak distribution in frequency space at each time-section n. Correspondingly, the constructed mask operator provides a simple time-varying filter that sets all outside Gabor coefficients to zero. To ensure the reconstruction is as close as possible to the ideal signal within the masked region in Gabor space, an iteration procedure is employed. After k-th iteration, we obtain the reconstructed time series Xg(t):

$$X_g(t) = \{\Gamma^{-1}\,\Phi\,\Gamma\}^k\ X(t) = \Theta^k\ X(t)$$

where Γ and Γ^{-1} denote a forward and inverse Gabor transform in discrete time–frequency lattice space respectively. This process will converge as long as the

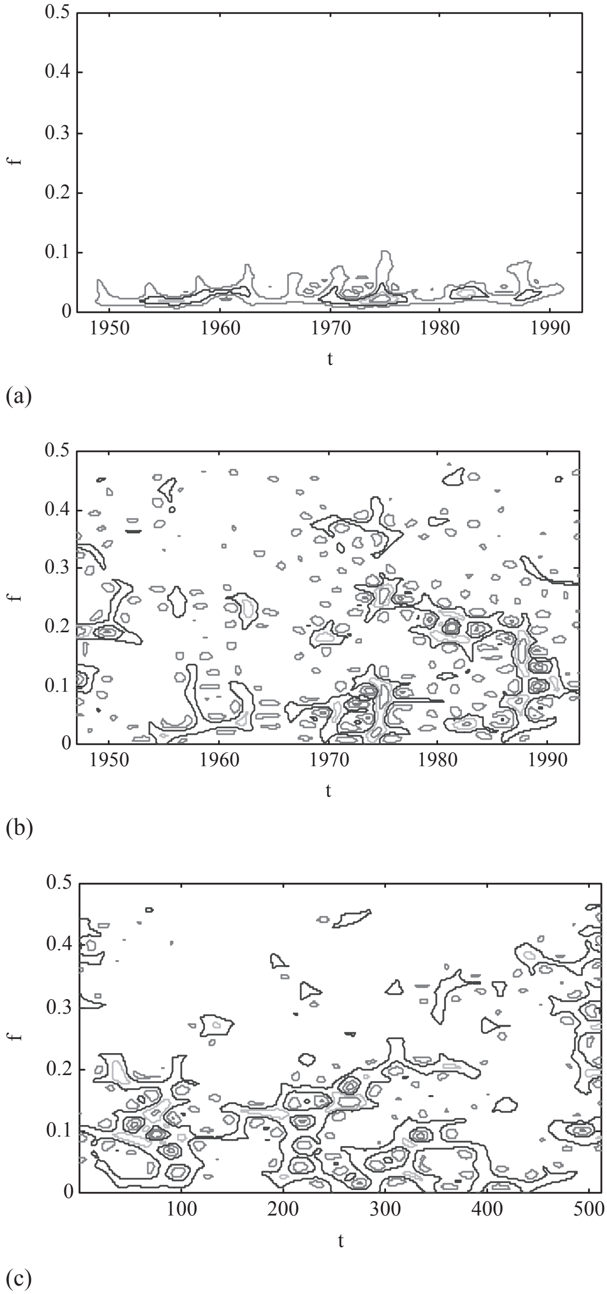


Figure 6.2 Time–frequency representation of empirical and simulated series from FSPCOM logarithmic detrended data. (a) HP cycles. (b) FD series. (c) AR(2) model of FD series.

maximum eigenvalue of the matrix $\Theta = \{\Gamma^{-1}\Phi\Gamma\}$ is less than one (Sun *et al.* 1995). Our numerical calculation indicates that Θ converges in less than five iterations. The construction of the mask function in Gabor space is determined by the peak time section of Gabor distribution (see Figure 6.3).

In order to define the boundaries of a time-varying filter, the cut-off threshold C_{th} at each time section is introduced in the following way:

$$C_{th} = C_{mean} + H * C_{std}$$

Here, H is the only adjustable parameter in setting the mask function. C_{mean} is the mean value of $|C(m, n)|$; C_{std} is the standard deviation of $|C(m, n)|$, all calculations are conducted at the peak time section where $|C(m, n)|$ reaches the maximum value.

From Table 6.2, we can see that the decomposition of variance is not sensitive to the choice of H, because the signal energy is highly concentrated in the low frequency band and the energy surface is very steep in the Gabor space. The variance of the filtered (reconstructed) signal accounts for about 70 percent of total variance. We chose H = 0.5 in later tests.

The filtered HP cycles have clean features of a deterministic pattern while the filtered auto-regressive AR(2) series still has a random image (see Figure 6.4). Later we will see that the filtered HP cycles with a persistent frequency can be described by a color chaos with a low dimensionality.

Several statistics are calculated between the filtered and the original time series: η is the ratio of their standard deviation; υ is the percentage ratio of variance; CCgo is their correlation coefficient.

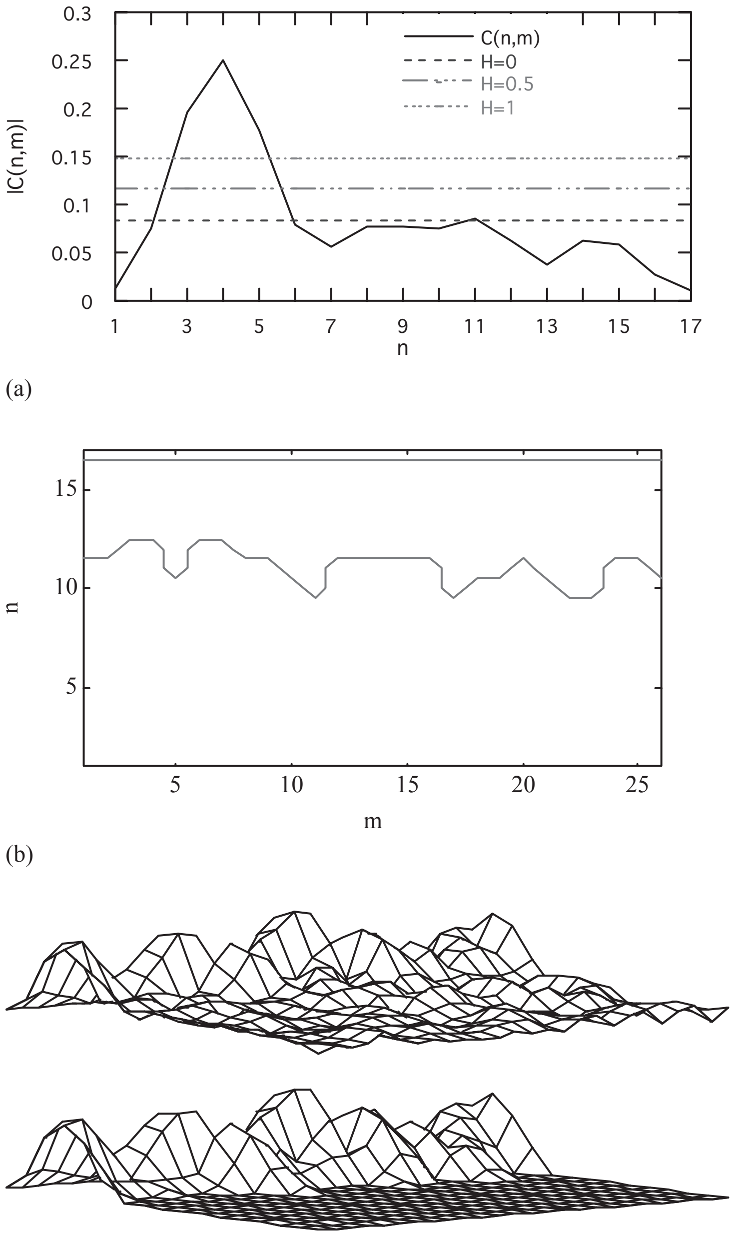
The shape of the mask function is determined by the intensity of Gabor components. We should point out that a conventional test, such as the Durbin-Watson residual test, may not be applicable here, because residuals may be color noise. Our main target is catching the main deterministic pattern in the time–frequency space, not a parametric test based on regression analysis.

The reconstructed HPc time series reveals the degree of deterministic approximation of business fluctuations: the correlation coefficient between the filtered and original series is 0.85. Their ratio of standard deviation, η is 85.8 percent for FSPCOM. In other words, about 73.7 percent of variance can be explained by a deterministic cycle with a well-defined characteristic frequency, even though its

Table 6.2 Decomposition of FSPCOM HPc for varying H

H	η	υ *(%)*	*CCgo*
0.0	0.8435	71.2	0.8595
0.5	0.8281	68.6	0.8471
1.0	0.8256	68.2	0.8461

Note
Here, η is the ratio of standard deviations of the reconstructed series $S_g(t)$ over the original HP cycles $S.(t)$; υ, their percentage ratio of variance.



(a)

(b)

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Figure 6.3 Construction and application of the time-variant filter in Gabor space. (a) Peak time-section of Gabor distribution in the frequency domain. (b) Mask function (H = 0.5). (c) The Gabor distribution for the unfiltered and filtered data.

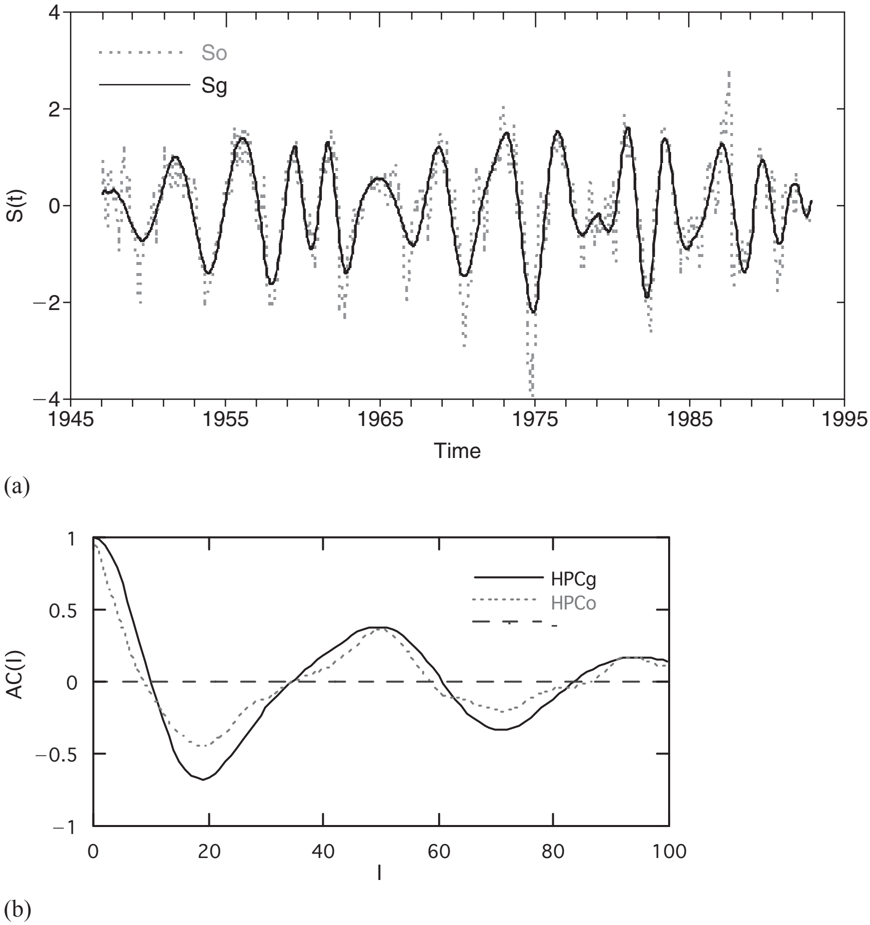


Figure 6.4 The original and reconstructed time series of HP cycles. (a) The original and filtered HP cycles (H = 0.5). (b) Autocorrelations of the original and reconstructed series.

amplitude is irregular. This is a typical feature of chaotic oscillation in continuous-time nonlinear dynamical models.

We can see that the phase portrait of filtered FSPCOM HPc cycles has a clear pattern of chaotic attractors, while the filtered AR(2) model fitting FSPCOMln FDs series still keeps its random image (Figure 6.5).

From Figure 6.5, we also confirm our previous discussion in section 6.2 that FD detrending simply amplifies high frequency noise while HP detrending plus the time-variant filter in Gabor space pick up deterministic signals of color chaos from noisy data.

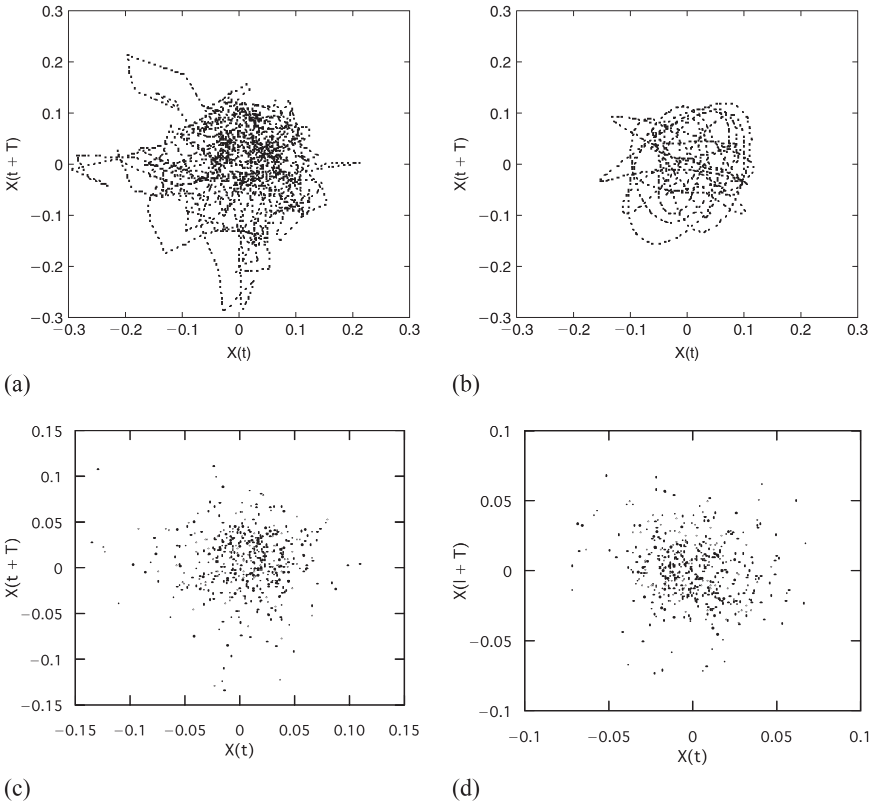


Figure 6.5 Patterns of phase portraits for FSPCOM series. (a) HPc unfiltered series. (b) HPc filtered series. (c) FD series. (d) Filtered AR(2) series.

6.6 Characteristic frequency and color chaos

Time–frequency representation contains rich information of underlying dynamics. At each section of time t, the location of the peak frequency f(t) can be easily identified from the peak of energy distribution in the frequency domain. If the time path of f(t) forms a continuous trajectory, we can define a characteristic frequency f_c from the time series. Correspondingly, we have a characteristic period P_c (= $1/f_c$). Stochastic time series such as the auto-regressive (AR) process cannot form a continuous line in time–frequency representation.

The empirical evidence of color chaos is further supported by consistent results from complementary nonlinear tests of filtered HP cycles (Table 6.3).

Characteristic frequencies of deterministic cycles are found in HP detrended cycles. Their frequency variability, measured by the ratio of standard deviation to mean frequency, are about 25 percent over a history of 45 years. The frequency stability of business cycles in the stock market is quite remarkable. The

Table 6.3 Characteristic statistics for stock market indicators

Data	η	υ *(%)*	*CCgo*	*Pc*	ϕ*(%)*	P_{dc}	λ^{-1}	μ
FSPCOM	0.828	68.6	0.847	3.6	25.9	3.3	5.0	2.5
FSDXP	0.804	64.6	0.829	3.5	27.7	2.9	6.9	2.4

Notes
Here, η is the ratio of standard deviations of the reconstructed series $S_g(t)$ over the original HP cycles $S.(t)$; υ, their percentage ratio of variance; CC_{go}, their correlation coefficient (also in the Table 6.2). P_c, is the mean characteristic period from time–frequency analysis; P_{dc}, the decorrelation period from correlation analysis; ϕ, is the frequency variability (in time) measured by the percentage ratio of the standard deviation of f_c to the mean value of f_c over time evolution; λ is the Lyapunov exponent, its reverse λ^{-1} is also a measure of a time scale, which is in the same range of P_{dc} for deterministic cycles. μ is the correlation dimension for attractor. The time unit is year.

bandwidth of the characteristic frequency fc for HPc cycles is just a few percent of the frequency span of white noise. This is strong evidence of economic color chaos even in a noisy and changing environment.

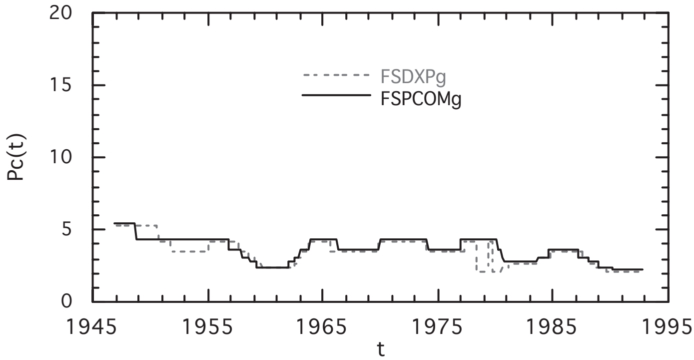
From Table 6.3, we can see that FSPCOM and FSDXP are quite similar in frequency pattern and dimensionality. The characteristic period P_c from the time–frequency analysis and the decorrelation period P_{dc} from the correlation analysis are remarkably close. It is known that a long correlation is an indicator of deterministic cycles (Chen 1988a, 1993a). However, time–frequency analysis provides a better picture of persistent cycles in business movements than correlation analysis and nonlinear analysis based on time-invariant representations.

The frequency patterns of the stock market indexes disclose a rich history of market movements (Figure 6.6).

The extraordinary resilience of the stock market can be revealed from the stable frequency pattern under the oil price shocks in 1973, 1979, and the stock market crash in October 1987. These events generated only minor changes in the characteristic period P_c for FSPCOM and FSDXP indexes.

Economic historians may use the P_c path as a useful tool in economic diagnosis. After a close examination of Figure 6.6, we found that the frequency shifts of S&P indexes occurred after the oil price shock in 1973, but happened before the stock market crash in 1987. If we believe that the cause of an event always comes before the effect, then our diagnosis of these two crises would be different. The oil price shocks were external forces to the stock market, while the stock market crash resulted from an internal instability.

Our findings of nonlinear trend and persistent cycles reveal a rich structure from stock market movements. For example, the equity premium puzzle will have a different perspective because the frequency pattern of consumption and investment are not similar to that of stock market indicators (Mehra and Prescott 1985; Chen 1996b). We will discuss the issue in Chapter 7.



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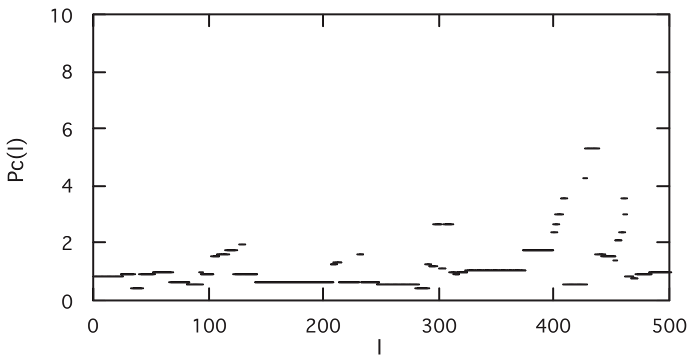


(b)

Figure 6.6 Time paths of instantaneous frequencies. (a) Frequency stability under historical shocks. (b) Filtered AR(2) series.

6.7 Risk, uncertainty, and information ambiguity

Franck Knight made a clear distinction between risk and uncertainty in the market (Knight 1921). Keynes also emphasized the unpredictable nature of "animal spirits" (Keynes 1925, 1936). From the view of nonequilibrium thermodynamics, uncertainty is rooted in time evolution in open systems (Prigogine 1980).

The random-walk model of asset pricing has two extreme features. On one hand, the turning point of future price path is completely unpredictable. On the other hand, the average statistics are completely certain because the probability distribution and its mean and variance is known and unchanged. According to equilibrium theory, only measurable risk with known probability exists in the stock market, no uncertainty with unknown and changing probability is considered in asset pricing models. The static picture of CAPM (capital asset pricing model) ignores the issue of uncertainty raised by Knight and Keynes.

Both practitioners and theoreticians are aware of the impact of business cycles. Fischer Black, the originator of the geometric random-walk model in option pricing theory, made the following observations (emphasis added by the author) (Black 1990):

> One of the [Black–Scholes] formula's simple assumption is that the stock's future volatility is known and constant. Even when jumps are unlikely this assumption is too simple. *Perhaps the most striking thing I found was that volatilities go up as a stock prices fall and go down as stock price rise*. Sometimes a 10 percent fall in price means more than a 10 percent rise in volatility … After a fall in the stock price, *I will increase my estimated volatility even where there is no increase in historical volatility*.

From Black's observation, the implied volatility, the only unknown parameter in option pricing theory, does not behave as a slow changing variable, that is a necessary condition for meaningful statistic concepts of mean and variance, but acts like a fast changing variable, such as trend-shifting and phase-switching in business cycles (see also Fleming *et al.* 1994). Clearly, the up-trend or down-trend of price levels strongly influence the market behavior, even when historic variance may not change significantly. Black's observation of changing implied volatility helps our studies of nonlinear trends and business cycles in the stock market. We will discuss the issue in the near future.

In the equilibrium theory of CAPM, risk is represented by the variance of a known distribution of white noise. From our analysis, the risk caused by high frequency noise only accounts for about 30 percent of variance from FSPCOM and FSDXP HP cycles.

According to our analysis, there is an additional risk generated by a chaotic stock market. About 70 percent of variance from HP detrended cycles is associated with color chaos whose characteristic frequency is relatively stable. For the last 45 years, the variability of the characteristic period for FSPCOM and FSDXP is less than 30 percent. From this regard, the discovery of color chaos in the stock market indicates a limited predictability of turning points. We can develop a new program of period-trading and trend-trading in addition to level-trading strategy in investment decision and risk management. The frequency variability implies a forecasting error in a range of a fraction of the observed characteristic period. Clearly, the knowledge of HP cycles does little help for short-term speculators. Further study of higher frequency data is needed for investors and macro policy makers.

Recent literature of nonstationary time series analysis such as ARCH and GARCH models focus on the issue of a changing mean and variance in the random-walk model with a drift. We found two more sources of uncertainty: changing frequency and shifting trend in an evolving economy. These uncertainties severely restrict our predictability of a future price trends and future frequency of business cycles. Therefore, we have a new understanding of roots of animal spirits and difficulties in economic forecasting.

In the two-dimensional landscape of time–frequency representation, there is no absolute dividing line between stochastic noise and deterministic cycles. The concept of rational behavior can only be applied when the risk can be measured by a known distribution, such as a normal distribution in CAPM or a log-normal distribution in option pricing theory. The question of information ambiguity arises in signal processing when information is a mixture of deterministic and stochastic signals. Under the Wigner distribution, excess information with an infinite order of K coupling produces misleading interferences and false images. The real challenge in pattern recognition is searching pertinent information from conflicting news and experiences. For example, the merger and acquisition in the capital market is a war game in the business world filled with conflicting and false information. The stock market often overreacts to market news on merger and acquisition. There is no such thing of perfect information and rational expectations in a complex world mixed with nonlinearity and uncertainty. That is why information judgment (filter) and strategic choice is critical to market survival.

From our analysis of historical events, the time path of stock prices is not a pure random walk. Price history is a rich source of new information if we have the right tools of signal decoding. In balance, our approach of trend–cycle decomposition and time–frequency analysis increases a limited predictability of chaotic business cycles, and at the same time reveals two more uncertainties in nonlinear trends and evolving frequency.

The equilibrium school in finance theory emphasizes the forecasting difficulty caused by noisy environments, but ignores the uncertainty problem in evolving economies.

6.8 Persistent cycles and the Friedman paradox

A strong argument against the relevance of economic chaos comes from the belief that economic equilibrium is characterized by damped oscillations and absence of deterministic patterns. Friedman asserted that market competition will eliminate the destabilizing speculator, and speculators will lose money (Friedman 1953b). Friedman did not realize that arbitrage against a market sentiment is very risky if rational arbitrageurs have only limited resources (Shleifer and Summers 1990). Friedman also assumed that winner-followers could perfectly duplicate a winner's strategy. This could not be done for chaotic dynamics in an evolving economy.

People may ask what will happen once the market knows about the limited predictability of color chaos in the stock market? At this stage, we can only speculate the outcome under complex dynamics and market uncertainty. We believe that the profit opportunities associated with color chaos are limited and temporary, but the nonlinear pattern of persistent cycles will remain in existence and evolve over time.

Based on our previous discussion, we will point out two likely outcomes: coexistence of diversified strategies and persistence of chaotic cycles. There is no way to have a sure winner, because of trend uncertainty and information ambiguity. Nonlinear overshooting and time-delay in feedback may actually create the chaotic cycles in the market dynamics (Chen 1988a, 1993a; Wen 1993).

There are several factors that may prevent wiping out the persistent pattern of color chaos. First, people are incapable in distinguishing fundamental movements and sentimental movements in price changes, especially when facing a changing trend. The same argument on a monetary veil of real income caused by inflation can be applied to a price veil of stock value caused by a changing market sentiment along with an evolving economic growth. Second, information ambiguity is caused by a limited time horizon in observation of complex systems. Bounded rationality is rooted not only in limited computational capacity, but also in dynamic complexity (Prigogine 1993).

Winner-following or trend-chasing behavior may change the amplitude or frequency of a color chaos, but the chaotic pattern will persist in a nonlinear and nonequilibrium world.

6.9 Conclusion

There is no question that external noise and measurement errors always exist in economic data. The questions are whether some deterministic pattern and dynamical regularities are observable from the economic indicators and whether economic chaos is relevant in economic theory (Granger and Teräsvirta 1993). Our answer is yes if the color-chaos model is addressing the empirical pattern of business cycles.

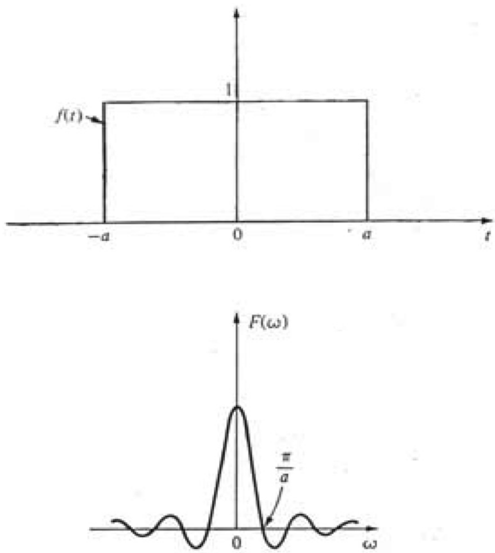
From our empirical analysis, stock market movements are not pure random walks. A large part of stock-price variance can be explained by a color-chaos model of business cycles. Its characteristic frequency is in the range of business cycles. The frequency stability of the stock market is remarkable under historical shocks. The existence of persistent chaotic cycles reveals a new perspective of market resilience and new sources of economic uncertainties. To observe chaotic patterns of business cycles, a proper trend–cycle decomposition and a proper time window is the key in economic signal processing. We need a modified theory of asset pricing in a chaotic stock market.

A new way of thinking needs new representation. From business practice, it is known that the time window plays a critical role in evaluating key statistics, such as mean, variance, and correlations in asset pricing. Under a coherent wave representation, such as the case in quantum mechanics and information theory, the frequency window is closely related to the time window according to the uncertainty principle (Gabor 1946). That is why the joint time–frequency representation is essential for time-dependent signal processing.

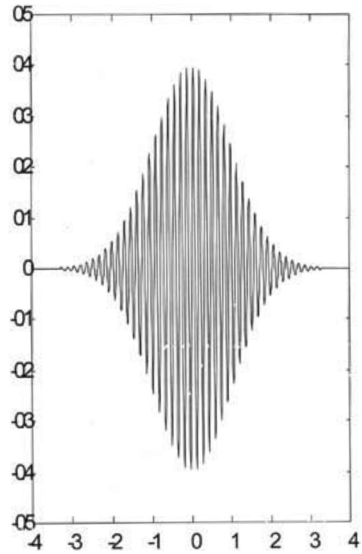
Like a telescope in astronomy or a microscope in biology, time–frequency analysis opens a new window of observing evolving economies. The WGQ algorithm greatly increases the analytic power in analyzing noisy data with limited time series. As a building block of nonlinear economic dynamics, the color-chaos model of stock market movements may establish a link between business-cycle theory and asset-pricing theory.

6.10 Appendix: the uncertainty principle and Gabor space

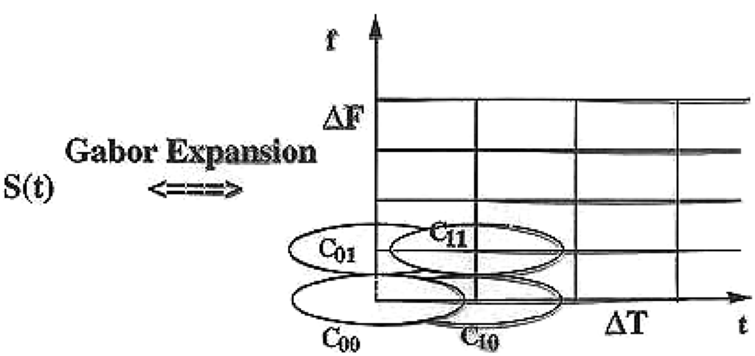
This appendix provides a visual representation of the uncertainty principle in time and space, which is the very foundation of Gabor space in time frequency analysis (see Figure 6.7)



(a)



(b)



(c)

Figure 6.7 Construction of the Gabor space based on the uncertainty principle in time and frequency. (a) The uncertainty principle in time and frequency. (b) The Gabor wavelet (coherent state in quantum mechanics). (c) The Gabor space in discrete time and frequency lattice space.

From Figure 6.7a, the half-width of the time window is a, while the half-width of the frequency window is

$$\left(\frac{\pi}{a}\right).$$

Therefore, the smaller of the time window (i.e., the time resolution) leads to the larger frequency window (i.e., the frequency resolution). The smallest uncertainty is achieved both in time and frequency domain when the envelope of the harmonic waves is a Gaussian function (see Figure 6.7b), which is called the Gabor wavelet or the coherent state in quantum mechanics. Gabor space is a two-dimensional lattice space in discrete time and space (see Figure 6.7c). At each time grid, the base function is a Gabor wavelet with a specific frequency. A time series can be described by an Gabor expansion in Gabor space in time and frequency.

The advantage of time frequency analysis in Gabor space lies in the fact that the best resolution in time and frequency can be achieved by the special base function – the Gabor wavelet. According to the uncertainty principle, the smallest uncertainty is satisfied only under the Gaussian envelope of the harmonic waves.

Acknowledgments

The software of time–frequency distribution is developed and modified by Shie Qian and Dapang Chen. The application of the HP filter was suggested by Victor Zarnowitz. The Hodrick–Prescott algorithm is provided by Prof. Finn Kydland. Their help is indispensable to our progress in empirical analysis.

Notes

Preface

1 Paul A. Samuelson passed away on December 13, 2009. We lost a great mind, who was not only a founder of mathematical economics and neo-classic synthesis in the 1940s, but also an early supporter of studies in economic chaos. We are unfortunate not to have him reading our book before publication. We can still share his insights on the future development of economics after this crisis.

Few economists know that Samuelson himself developed a chaos model in micro utility theory (1986, 1990). But his strong interest in empirical evidence of economic chaos was more visible from his letters to the author dated June 8, 1987 and December 22, 1987, in which Samuelson showed cautious interest in our early work on monetary chaos and raised the issue of how to distinguish deterministic chaos with other candidates such as fractal and Pareto-Levy distributions. He kindly offered his advice to the younger generation of economists, when he said: "My various remarks should not throw cold water on your pioneering efforts. However, there is a role for tough mindedness and self-criticism along with a role for daring in science." After we found wide evidence of color chaos from macro and stock indexes, Samuelson asked the author if we could develop a more general framework so that neo-classical models could be integrated as special cases in a general nonlinear theory. This is a grand task, once Keynes aimed to parallel Einstein's approach in his general theory (Galbraith 1994).

Samuelson's foresight was his keen sense of paradigm shift in economic science, which was revealed by his letter to Dr. Linda Reichl, the acting director for the Ilya Prigogine Center for Statistical Mechanics and Complex Systems at University of Texas at Austin, dated September 20, 1995, for evaluation of Ping Chen's work for academic promotion. After his positive evaluation, his letter made a further remark:

> What cannot be predicted at this time is whether one or another of his innovative paradigms will turn out to be of great moment to the corps of leading mainstream economists. He is in the queue of promising researches but whether his lottery ticket contains a winning number – only the future can tell.

Honestly speaking, we were still worried about possible applications of economic chaos when Samuelson already considered the issue of innovative paradigm. We realized the need of paradigm change after the Asian financial crisis and transition depression in EEFSU (see Chapter 2).

In his last interview on June 17, 2009, Samuelson once more emphasized the lesson for economists from the Great Depression: "That was a disequilibrium system. I realized that the ordinary old-fashioned Euclidean geometry didn't apply" (Clark 2009).

I wish that our younger readers could continue the cause pioneered by Keynes to develop a general theory of nonlinear nonequilibrium economic dynamics, so that we could better understand the viable nature of the market and the proper role of governments and society as integrated parts of the modern mixed economy.

This note was added by Ping Chen on December 19, 2009 in memory of Paul Samuelson.

2 Equilibrium illusion, economic complexity, and evolutionary foundation in economic analysis

1 Originally published in (2008) *Evolutionary and Institutional Economic Review*, 5(1), 81–127 (Japan).
2 In Chapter 16, the relative deviation is renamed as market variability (MV) as a feature measurement of market stability.

3 Evolutionary economic dynamics: persistent cycles, disruptive technology, and the trade-off between stability and complexity

1 This is the chapter 15 in Kurt Dopfer edited, *The Evolutionary Foundations of Economics*, pp. 472–505, Cambridge University Press, Cambridge (2005).
2 Edward Prescott told the author at the AEA2001 meeting that the HP filter was first used by John von Neumann.
3 This ratio is called the coefficient of variation (CV) in statistics and unitized risk in finance literature. We call it the relative deviation with a comparison when we consider the standard deviation as the absolute deviation. This term makes a sense from physics perspective. Later in Chapter 16 section 16.5, we rename it as the market variability (MV). MV is a better macro indicator since it is more stable than the conventional measure of variance in asset pricing theory.
4 "Work" is a physics term, which means the amount of "effective energy" transferred into "mechanical work" measured by the "acting force" times the "traveling distance." In contrast, the "wasted energy" measured by the "heat" energy or "transaction cost" in economics term.
5 The uncertainty principle in quantum mechanics implies that the minimum amount of energy is needed for getting information on particle's speed and position, or time and energy (Brillouin 1962). In this regard, the concepts of perfect information and rational expectation in macro dynamics are against the uncertainty principle in quantum mechanics. Therefore, the so-called rational expectations demand infinite information without costing infinite energy. This scenario is impossible in a realistic physics world. In order to develop an empirical science of economics, we need a general theory, which is consistent with laws of physics and constraints in ecology and biology.

4 Empirical and theoretical evidence of economic chaos

1 Originally published in (1988) *System Dynamics Review*, 4(1–2): 81–108.
2 After the publication of this article, we were informed by economists that there was a fundamental debate between Austrian school and monetarist school. Austrian school believed that monetary movements were endogenous in nature, while monetarists claimed that monetary movements are exogenous. Interesting readers could study the writings by Friedrich Hayek (1933) and Milton Friedman. Monetarists relied on their analysis on statistics based on linear regression analysis. Austrians thought that simple (linear) mathematics was not capable of understanding social phenomena. We found out that new tools of nonlinear dynamics could address the old debate on the nature of business cycles. It turned out that our discovery of monetary chaos is an evidence of endogenous monetary cycles and our model of soft-bouncing oscillator is capable of understanding sources of endogenous business cycles.

5 Searching for economic chaos: a challenge to econometric practice and nonlinear tests

1 In Richard Day and Ping Chen (Eds.) (1993) *Nonlinear Dynamics and Evolutionary Economics*, Chapter 15, pp. 217–53, Oxford: Oxford University Press.

6 A random walk or color chaos on the Stock Market? Time–frequency analysis of S&P indexes

1 Originally published in (1996) *Studies in Nonlinear Dynamics and Econometrics*, 1(2): 87–103.

2 The original symbol was the Greek letter λ used by the originator (Hodrick and Prescott 1997). We use the Latin letter s for the smoothing parameter to avoid confusion with the symbol of Lyapunov exponent λ in our writing. The HP filter was previously studied by Italian astronomer Schiaparelli in 1867 (Stigler 1978) and Hungarian mathematician and physicist von Neuman in the ballistic literature (von Neuman *et al.* 1941).

3 The numerical algorithm is called the time–frequency distribution series (TFDS). The computer software is marketed by National Instruments under the commercial name of Gabor spectrogram as a tool kit in the Lab View System. We prefer to call this analytical algorithm the WGQ (Wigner–Gabor–Qian) transform in physics conversion.

7 Trends, shocks, persistent cycles in evolving economy: business-cycle measurement in time–frequency representation

1 In W.A. Barnett, A.P. Kirman, and M. Salmon (eds.) (1996) *Nonlinear Dynamics and Economics*, Chapter 13, pp. 307–31, Cambridge, Cambridge University Press.

8 Origin of division of labor and stochastic mechanism of differentiation

1 Originally published in (1987) *European Journal of Operational Research*, 30(3): 246–50.

9 Imitation, learning, and communication: central or polarized patterns in collective actions

1 Originally published in A. Babloyantz (ed.) (1991) *Self-Organization, Emerging Properties and Learning*, pp. 279–86, New York: Plenum.

10 Needham's question and China's evolution: cases of nonequilibrium social transition

1 In George P. Scott (ed.) (1990) *Time, Rhythms, and Chaos in the New Dialogue with Nature*, Chapter 11. pp. 177–98, Ames Iowa: Iowa State University Press.

11 China's challenge to economic orthodoxy: Asian reform as an evolutionary, self-organizing process

1 Originally published in (1993) *China Economic Review – An International Journal*, 4(2): 137–42.

12 The Frisch model of business cycles: a spurious doctrine, but a mysterious success

1 Originally (1999) *IC2 Working Paper* 99–05–01, University of Texas at Austin, USA; and CCER Working Paper 1999-007, China Center for Economic Research, Peking University, Beijing, China.

13 Microfoundations of macroeconomic fluctuations and the laws of probability theory: the Principle of Large Numbers vs. rational expectations arbitrage

1 Originally published in (2002) *Journal of Economic Behavior and Organization*, 49(3): 327–44. Received 8 March 1999; received in revised form 4 September 2001; accepted 6 September 2001.

2 This ratio is called variation coefficient in statistics and finance literature when the mean is positive. Mathematically speaking, this is a dimensionless number, which can be called "the relative deviation" comparing to the standard (absolute) deviation. In macroeconomic analysis, this ratio can be considered as a salient indicator of "market variation" in business cycles and financial volatility.

3 The pattern of

$$\frac{1}{\sqrt{N}}$$

is well known in physics and biology literature (Schrödinger 1944) under various technical terms, such as the relative magnitude of fluctuation (Reif 1964), the root-mean-square relative fluctuation about the mean (May 1974a), and the fractional deviation (Reichl 1998). The terms "relative deviation," "Principle of Large Numbers," and "positive variable" are used by the author for general readers in understanding the points at issue.

4 We made one mathematical simplification for the LMI model. Here, our allocation variable ϕ is

$$\left(\frac{\vartheta}{2}\right)$$

in the original LMI formulation. Other symbols in this section are the same as the LMI model for the reader's convenience.

14 Complexity of transaction costs and evolution of corporate governance

1 Originally published in (2007) *Kyoto Economic Review*, 76(2): 139–53.

15 Market instability and economic complexity: theoretical lessons from transition experiments

1 In Yang Yao and Linda Yueh (eds.) (2006) *Globalisation and Economic Growth in China*, Chapter 3. pp. 35–58, Singapore: World Scientific.

16 From an efficient to a viable international financial market

1 In R. Garnaut, L. Song, and W.T. Woo (eds.) (2009) *China's New Place in a World in Crisis: Economic, Geopolitical and the Environmental Dimensions*, Chapter 3. pp. 33–58, Australian National University E-Press and The Brookings Institution Press, Canberra.