Economic Complexity and Equilibrium Illusion

Essays on market instability and macro vitality

Ping Chen

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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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Preface

We are in the midst of the Grand Crisis (this is a term in parallel with the Great Depression in the 1930s). In Chinese, crisis (*wei-ji*) means danger (*wei*) and opportunity (*ji*). This is the main idea of order out of chaos introduced by the late Belgian physicist Ilya Prigogine (Prigogine and Stengers 1984). In economic literature, instability is mainly used as a negative term. But the physics concepts of nonequilibrium, complexity, and chaos imply not only the destruction of an old order, but also the emergence of a new structure. From this perspective, the current Grand Crisis may bring about a new world of economic order and a new era of economic thinking.

"The whole intellectual edifice collapsed in the summer of last year," the perplexed former Federal Reserve Chairman Alan Greenspan confessed in congressional testimony on October 23, 2008 (Greenspan 2008). Changing historical currents demand changes in economic paradigm. Media commentaries and prominent economists soon identified two failed theories in mainstream economics: the efficient market hypothesis in finance and the microfoundations theory in macroeconomics, which is the core of the counter Keynesian revolution in last three decades. Among critics of market fundamentalism, only some weak voices of information asymmetry and behavioral finance have been heard. Justin Fox, an economics columnist for *Time* magazine, documented a series of intellectual failures in a recent book on the myth of rational markets (Fox 2009). He laments the lack of any alternative "grand new theory" and finds that the debate has resulted in a "muddle."

However, Fox's complaint is not quite true. His bounded knowledge is a good example of incomplete information or even distorted information in the mainstream media. This book of collected essays demonstrates that there are better alternatives in understanding market instability and economic crisis, and a new paradigm has been developing for the last three decades. Only the exclusive attitude of mainstream economics has marginalized new ideas and new approaches in economic literature and university textbooks.

This Grand Crisis revives old philosophical debates between Keynes and classical economists, between Hayek and Friedman, between Schumpeter and Frisch, between Minsky and Lucas, on the nature of business cycles and financial crisis. Moreover, it revitalizes new methodological contests among econometricians, mathematicians, and physicists in analyzing economic time series. Generally speaking, there are at least three, not just two competing schools of thoughts.

The first is the equilibrium economics or neo-classical school. Its core belief is the so-called efficient market with rational expectations, which is self-stabilizing without need of government intervention. Any disturbance in the market is external and temporary in nature. Brownian motion or random shocks are their mathematic formulation of laissez-faire policy. There is a long cast of prominent names associated with this school: Ragnar Frisch, Milton Friedman, Eugene Fama, Robert Lucas, etc. Their arguments are based on methodological individualism, often in the form of a representative agent. Their main instrument in creating an equilibrium illusion is the first differencing (FD) filter in econometric practice, which wrongly targets the short-term fluctuations outside the business cycle frequency. Its deficiency is parallel to the geocentric system of the Ptolemy model in astronomy.

The second is the disequilibrium economics or Keynesian school. Its central theme is a fragile market, which frequently collapses under irrational panic or historical events. Known scholars in this camp include John Maynard Keynes, Hyman Minsky, Benoît Mandelbrot and behavioral economists. Their main effort is introducing social psychology into economic behavior (Akerlof and Shiller 2009). However, they have not yet developed a consistent theoretical framework. They experiment with various mathematical models, ranging from Levy distribution, fractal Brownian motion, unit roots, co-integration, sunspot, sand-pile, to power law in econophysics. Monetary and fiscal policies are the main tools for restoring market confidence from time to time. Their weakness is a lack of structural analysis and historical perspective. They often shared the problem of the whitening device (FD) in analyzing economic time series.

The third school is the self-organization economics or evolutionary school. Its perception of market economy and division of labor can be characterized as a viable market. Schumpeter's ideas of creative destruction, economic organism, and biological clock, and Hayek's concept of spontaneous order, are remarkably similar to Prigogine's idea of self-organization and dissipative structure in complexity science. Their characteristic is a biological view in an historical perspective for understanding human society. The term "viable market" was inspired by the observation of a firm's "viability" by Justin Lin, a former colleague at Peking University and now the Chief Economist at the World Bank (Lin 2009). Before the late 1970s, this school was overlooked by the new wave of econometrics and mathematic economics since the evolutionary perspective is difficult to be formulated by a linear stochastic model and optimization algorithm. Since the late 1970s, the new science of nonlinear dynamics and complex systems provided new tools in modeling biological and economic behavior. Our discovery is that a proper separation of trend and cycles is critical in studying an endogenous mechanism in business cycles. Our contribution is introducing nonlinear population dynamics with resource constraints as a unified framework in modeling micro, macro, finance, and historical evolution. Market movements do not like random walk with stable mean value but short correlations. The linear stochastic model in macro and finance economics implies no internal structure and historical constraints in industrial economy. The equilibrium illusion of self-stabilizing market is created by a white looking glass, the first differencing (FD) filter, which distorts any colorful picture into a white image. In the history of science, the telescope helped Galileo to prove the Copernicus heliocentric theory of planet motion. In economic analysis, our discovery of economic color chaos (color means a narrow frequency band against a noisy background) reveals a new world of macro vitality. The movements of stock market and macro indexes can be better understood by a mix of nonlinear trend, persistent cycles, plus minor noise. The market trend is mainly driven by technological wavelets and changing economic structure. Persistent cycles in the US economy are endogenous and nonlinear in nature, which fall within the stable range of NBER business cycles from two to ten years. The sources of business cycles are not microfoundations, but meso foundation in financial intermediate and industrial organization. Financial market is inherently unstable because of collective behavior, financial leveraging, nonlinear pricing, and power concentration. For a viable market with resilient frequency but erratic fluctuations, the government's role in managing and regulating economy should be more like a family doctor treating his patients rather than a school teacher dealing with pupils. He should care more about the system's health and structural malfunction than day to day instructions to pupils. It was Paul Samuelson, who predicted as early as 1995 in an evaluation letter of our work that new innovative paradigms might have a chance to stand an historic test in mainstream economics (Samuelson 1995).[1]

Unlike dramatic events of the Great Depression and the Grand Crisis, our adventure quietly started from two fundamental issues: the first is the so-called Joseph Needham's question of why science and capitalism emerged in Western Europe, not in China or other civilizations. The second is studying the nature of business fluctuations. Should we characterize them by random noise or deterministic chaos? The first issue shifted my interest from the heights of the culture revolution in China to Ilya Prigogine's new thermodynamics of evolution in 1973. I ended up studying and working with Prigogine from 1981 until his death in 2003. My studies of evolutionary dynamics were inspired by Peter Allen (a member of the Brussels school led by Prigogine), while my research of economic chaos was initiated by Ilya Prigogine. Without the intellectual culture at the Ilya Prigogine Center for Statistical Mechanics and Complex Systems at University of Texas at Austin, our endeavor cannot survive under the monotone atmosphere dominated by neo-classic economics. When I started teaching at Peking University in 1997, my focus moved from technical algorithms to fundamental principles behind policy issues. The striking difference between China and EEFSU (East Europe and former Soviet Union) during the economic transition induced me to examine basic assumptions in equilibrium economics, which turned out to be mathematic toy models rather than scientific theories.

With a basic knowledge in calculus and science, college students, economic teachers, and general readers alike should easily follow our journey to explore economic complexity and test competing economic theories. Here, complexity means nonlinear interaction, nonequilibrium diversity, many-body problem, nonstationary dynamics, and path dependence, while simplicity implies linearity, equilibrium convergence, stationary model, and one-body problem (of representative agent). Nonlinear modeling of economic complexity provides new tools in understanding economic structure, history, and evolution. You may realize that an economy is more like a living system. Its vitality is characterized by life rhythms. Thoughtful economists may be surprised that the dominant belief in self-stabilizing market, promoted by Frisch, Friedman, Fama Lucas, and Coase, are purely an equilibrium illusion, made up by the FD filter, the representative agent, the bilateral exchange, and even a perpetual motion machine in economic theory. Economic complexity, with emerging property and resilient dynamics will completely reshape our framework of economic thinking.

Like biology and physiology, structure matters immensely in understanding economic dynamics as a whole system. Adam Smith realized that division of labor is limited by market extent (1786, 1981), while Thomas Malthus pointed out the biological constraint to human activity (1798). Therefore, market-share competition is more fundamental than price competition, which serves a business strategy in market-share competition. Competition policy and structural reform are more essential than fiscal and monetary policy for developing a sustainable economy. The conventional micro–macro analysis ignores the middle layer of meso economics, i.e., financial intermediate and industrial organization, which are the foundations of creative destruction and business cycles. The irrational fads and panics in behavioral finance can be understood by interactions among individual actors. A consistent framework of ecology-socio-economic dynamics in continuous time is developing for micro, meso, macro, and Clio economics. Readers could judge if there is a better alternative to equilibrium economics based on individual rationality in discrete time.

Policy makers and the general public would find fresh ideas for understanding historical puzzles and contemporary events, such as the cultural diversification between East and West in the Middle Ages, the rise of China, the decline of EEFSU, and policy effectiveness in dealing with an economic crisis.

We are witnessing ongoing events of the Grand Crisis which originated in the core of a capitalist economy and turned into a global crisis. It is an historical moment to advance our economic knowledge. Economics in the twenty-first century will stand on the shoulders of giants. We have learned from visionary thinkers like Schumpeter, Keynes and Prigogine, as well as failed attempts by Frisch and Lucas. Economics as an empirical science will reach a new height and go beyond the scope of physics and biology in the future.

Finally, I should point out that all the papers here are kept in the original form as much as possible. I made some corrections in symbols and English for clarity and consistency. I also updated the references. If readers find mistakes in my book, please email: pchen@ccer.pku.edu.cn. I appreciate your critique and comments.

Ping Chen
July 27, 2009 at Austin, Texas
The 20th birthday of my younger daughter Vivian, a vibrant and critical student

Acknowledgments

Looking back, we are surprised how far we have gone when our research has been led by a visionary perspective. This volume is a humble memory for my late teachers, Ilya Prigogine, Walt Rostow, and Robert Herman. I am also indebted to my teachers and colleagues in Austin and Brussels, especially Peter Allen, Linda Reichl, William Schieve, Jack Turner, Werner Horsthemke, Gregoire Nicolis, and Luis Deneubourg.

I was trained as a physicist but turned into a self-educated economist. My knowledge of modern economics is mainly from dialogues with distinguished economists and social scientists, including William Barnett, David Kendrick, John Sterman, Eric Mosekilde, Paul Samuelson, Robert Solow, Richard Day, Michael Woodford, William Brock, Victor Zarnowicz, Finn Kydland, James Galbraith, Edward Prescott, Douglas North, Steven Cheung, Robert Heckman, Gregory Chow, Duncan Foley, Willi Semmler, Jeffrey Sachs, Ulrich Witt, Kurt Dopfer, George Soros, Joseph Stiglitz, Edmund Phelps, Robert Mundell, Gary Becker, Vernon Smith, Kenneth Arrow, Robert Fogel, Giancarlo Gandolfo, Charles Goodhart, Barkley Rosser, Paul Davidson, Augus Maddison, Immanuel Wallerstein, Elizabeth Perry, Philip Huang, Richard Baum, Shuji Cao, Stewart Schwab, William Black, Raoul Weiler, Pierre Calame, Grzegorz Kolodko, Yagi Kiichiro, Yuji Aruka, Luiz Carlos Bresser-Pereira, Dalin Tong, Mingyu Wu, Chang-neng Xuan, Haizhou Huang, Ligang Song, Justin Lin, Deming Huo, Zhengfu Shi, Ziyuan Cui, Chang Liu, and Weiwei Zhang. I also benefited from discussion with fellow scientists Shie Qian, Dapang Chen, Weimou Zheng, Bailin Hao, Zuoxiu He, Yuankai Wen, and Benoît Mandelbrot. Many contributions are made by my students and coworkers at University of Texas at Austin and Peking University, including Kehong Wen, Zili Zhang, Huajun Li, Wei Zeng, Gao Xu, Yinan Tang, and Jicheng Jia.

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Finally, this volume is dedicated to my wife, Song Guohe Chen, for her endless love and constant inspiration in the risky journey of developing complex evolutionary economics.

Abbreviations

AC(I)	autocorrelations with time lag I
ARIMA	auto-regressive integrated moving averaging (model series)
ARMA	auto-regressive moving averaging (model series)
ASEAN	Association of Southeast Asian Nations, which was established in 1967
Brent	Brent (North Sea Crude Oil) index
CAPM	Capital Asset Pricing Model developed by Sharp (1964)
CDS	credit default swaps
CH	chaotic solution
CMEA	Council for Mutual Economic Assistance or Comecon (1949–1991), an international organization of EEFSU
CN	cluster number
Cn	cycle number, n = 1, 2, 3
CP	complex regime including alternative periodic and chaotic solution bands
CSAC	complex spectral analysis of correlations
CV	coefficient of variation
D	correlation dimension
DDM	Divisia monetary demand aggregates; DDM2, DDM3, DDL is Divisia monetary demand aggregate index (which is different from official simple sum index) for M2, M3, and M4(L) respectively (Barnett and Chen 1988)
DO	damped oscillation regime
DS	difference-stationary series, an econometric term for time series generated by FD (first difference) filter
DSM	Divisia monetary supply aggregates; for example, DSM2 is Divisia monetary supply aggregate index for M2 (Barnett and Chen 1988)
ECN	effective cluster number
EEFSU	East Europe and former Soviet Union
EMH	efficient market hypothesis
ENGT	endogenous growth theory
EO	explosive oscillation regime

EP	explosive regime in linear or nonlinear oscillator
EXGT	exogenous growth theory
EXRJAN	Japanese/US exchange rate
FD	first differencing (detrending) of logarithmic time series. The detrended data is also called DS (difference-stationary) time series. Its economic meaning is the logarithmic of rate of change in a time unit. The DS perspective implies the shortest time window, which is only one time unit of the observed time series. It makes an extreme assumption that the underlying system is stationary without growth trend. Only random deviation dominates system fluctuations.
FDI	foreign direct investment
FM1	money supply M1 index
FM2	money supply M2 index
FSDXP	S&P stock dividend yield (US) from Citibase
FSPCOM	S&P 500 stock price index (US) from Citibase
FYCP90	three month commercial paper rate (US)
FYFF	the Federal Funds rate (US)
FYGT10	ten-year Treasury note rate (US)
GCDQ	real durable consumption (US)
GCQ	total real consumption (US)
GDPC1	real GDP (US)
GDPQ	real gross domestic products (US)
GMYFM2	the monetary velocity (US)
GNP	gross national product
GP	Grassberger–Procaccia algorithm in calculating correlation dimension, which is one specific measure of fractal dimension
GPDIC1	the real domestic investment (US)
HP	Hodrick–Prescott filter (detrending). This perspective includes a nonlinear smooth (slow varying) trend and a cyclic movement around the trend. It implies a time window in the range of NBER business cycles from 2–10 years.
HPc	detrended cyclic series from HP filter
HPg	smooth growth trend from HP filter
i.i.d.	independent and identically distributed (random variable)
IMF	International Monetary Fund
IPP	Industrial Price Index for all goods
JAFEE	Japanese Association for Evolutionary Economics
LBMNU	hours of non-farm business (US)
LBOUTU	labor productivity (US)
LCD	logistic chaos in discrete time, which is generated by logistic map: $X(t + 1) = 4X(t) [1 - X(t)]$
LHUR	the unemployment rate (US)
LL	log-linear
LLD	log-linear detrending. The detrended data is also called TS

(trend-stationary) time series. The TS perspective implies the maximum time window. Its length covers the whole period of the observed time series. It also takes the simplest assumption that the growth rate is constant with an exponential growth trend.

LLc detrended cyclic series from log-linear detrending
LLg log-linear growth trend
LMI Lucas' model of an island economy
LV Lotka-Volterra wavelet
MC monotonic converging
MI monotonic increasing
MV market variability, calculated by relative deviation (RD), the ratio of standard deviation to its mean (for positive variable only)
N number of data points (observations)
NAIRU Non-accelerating inflation rate of unemployment
NBER National Bureau of Economic Research. Its business cycle chronology is the empirical base for macroeconomic analysis in the US.
NC number of clusters in calculating market variation
NGO non-government organization
NPL non-performing loans
NPO non-profit organization
PCECC96 real personal consumption (US)
PMA Petroleum Marketers Association
PO periodic oscillation
PZRNEW the consumer price index (US)
RBC real business cycle school, a theory in macroeconomics, which considers technology shocks (not monetary shocks) as the major driving force of business cycles in computation model of macroeconomy
RCC Rössler spiral chaos of continuous time. Rössler model is a system of three-dimensional differential equations: $dX/dt = -Y - Z$, $dY/dt = X + 0.2Y$, $dZ/dt = 0.2 - 5.7Z + XZ$ (Rössler 1976).
RD relative deviation
SBO the soft-bouncing oscillator with a control target and soft boundaries of floor and ceiling in feedback control (Chen 1988a)
SEZ special economic zone in China's reform and transition period
SOEs state own enterprises (China)
SPX the Standard & Poor's 500 price index from yahoo.finance, which is the same as FSPCOM in Citibase
SSM2 simple-sum monetary aggregate index for M2, which is used in Federal Reserve as official monetary index
ST steady state solution in a dynamic model
STFT short-time Fourier transform, which is the simplest version of time–frequency analysis
T time lag in phase portrait
Td decorrelation time measured by the time lag of the first zero in autocorrelation function

TFDS	time–frequency distribution series, which is a numerical algorithm developed for calculating WGQ transform
TS	trend-stationary series in econometric literature. A typical TS example is the log-linear detrending.
TVE	town and village enterprises in China
WD	Wigner distribution
WGQ	Wigner–Gabor–Qian transform, which is used in nonstationary time–frequency analysis
WTI	West Texas Intermediate Index

Symbols

A	time unit is year for annual time series.
b(n)	birth rate.
C	consumption.
CC_{go}	the correlation coefficient between the filtered (reconstructed in Gabor space) and unfiltered (original) time series.
C_{th}	the cut-off threshold at time-section of matrix C(m, n).
C(m, n)	matrix in Gabor space.
d	the maximum distance between interacting pairs of base functions in d-th order of decomposed Wigner distribution.
D	fractal dimension for an attractor. D is an integer for normal attractor.
E	government expenditure.
EVOLV	the evolution time in numerical algorithm of Lyapunov exponent (Wolf *et al.* 1985).
FDs	time series generated by logarithmic first differencing.
f_c	characteristic frequency from time–frequency analysis. $f_c(= 1/P_c)$.
$F(f, t)$	the time–frequency distribution function.
$f(t)$	the peak frequency.
g	the growth rate.
G	gain factor.
H	a preference parameter or social field.
HPc	cyclic series generated by the HP filter.
HPg	smooth growth trend generated by the HP filter.
I	investment.
k	population growth rate or learning rate.
K	the highest order of decomposed Wigner distribution.
LLc	cyclic series generated by the HP filter.
LLg	smooth growth trend generated by the HP filter.
M	time unit is month for monthly time series.
m	mean value.
M_i	effective carrying capacity of species i.
N	number of data points.
N_i	population size of species i.

N^*	implied number of degree of freedom or cluster number
P_c	the characteristic period from time–frequency analysis. $P_c(= 1/f_c)$.
P_i	the probability of frequency i.
P_{dc}	the decorrelation period from correlation analysis, which is four times of decorrelation time Td. Pc is in the same order of P_{dc}.
Q	time unit is quarter for quarterly time series.
q	order parameter.
R, r_i	the death rate or removal rate.
s	a positive smoothing parameter in the HP filter, which penalizes variability in the growth component series. The original symbol was λ used by the originator (Hodrick and Prescott 1997). We use s for smoothing parameter to avoid confusion with the symbol of Lyapunov exponent in our writing. The calibration of s aims to adjust the cyclic component of the observed time series so that its frequency is close to NBER business cycles. For US annual aggregate data, s = 400 for annual data, 1600 for quarterly, and 14,400 for monthly series.
s_i	effective growth rate.
T	the time lag in phase portrait.
Td	the decorrelation time, measured by the first zero of autocorrelation function. It is one-fourth of the basic period Pc for harmonic cycles.
T_{fd}	the decorrelation time for FDs series.
T_{hc}	the decorrelation time for HPc cycles.
T_κ	the relaxation time.
u	flipping frequency.
$\nu = \frac{dx}{dt}$	particle velocity.
W	the number of states in the frequency domain.
$w_{+-}(q)$, $w_{-+}(q)$	transition probability function in term of order parameter q
Xg(t)	the reconstructed (filtered) time series based on WGQ transform.
Y	output.
Z_i	the power intensity of frequency i.
α	risk attitude or culture factor ($-1 < \alpha < 1$). If $a > 0$, it is a measure of risk-aversion or collectivism; if $a < 0$, it is a measure of risk-taking or individualism.
β	overlapping coefficient.
β_i	effective competition coefficient of species i.
γ	discrete-time information entropy.
Δt	time interval in measuring time series.
ς	the degree of frequency instability.
η	the ratio of standard deviations of the filtered time series $S_g(t)$ over the unfiltered time series $S_g(t)$.
θ	a measure of coolness in collective atmosphere, it is cool for the situation of high social temperature.

κ	friction coefficient.
λ	the largest Lyapunov exponent. Note: λ^{-1} is a measure of a time scale, which is in the same order of the decorrelation time for a strange attractor.
μ	the correlation dimension for the measure of strangeness of a mathematical attractor (Grassberger-Procaccia 1983). For logistic chaos (LCD), $\mu < 1$; for Rössler chaos (RCC), $2 < \mu < 3$; for nonlinear delay-differential equation, the range of μ is varying widely depending on the model.
$\Xi(t)$	a continuous-time Gaussian white noise with zero mean and standard deviation of σ.
Π	interaction constant.
$\xi(t)$	white noise with standard deviation σ.
σ	standard deviation.
τ	time delay in delay-differential equation. τ = TAU in parameter space.
υ	frequency variability, measured by the percentage ratio of variance of the filtered time series $S_g(t)$ over the unfiltered time series $S_o(t)$.
ϕ	the frequency variability (in time) measured by the percentage ratio of the standard deviation of the changing frequency to its mean of the changing frequency over time evolution.
ψ	the normalization factor.
Ω	the relative deviation, i.e., the ratio of the standard deviation to the mean.
Ω^*	the potential relative deviation generated by N^* micro agents.
$\varpi_{ST} = \varpi$	the relative deviation in a static system for just one element at micro level.
$\Omega_{N,ST}$	stands for the relative deviation in a static system at macro level with N elements.
ω	angular frequency.
ω_1	realized angular frequency.

1 Introduction

> Fundamental ideas play the most essential role in forming a physical theory. Books on physics are full of complicated mathematical formulae. But thought and ideas, not formulae, are the beginning of every physical theory.
>
> Einstein (Einstein and Infeld 1938)

> The classical theorists resemble Euclidean geometers in a non-Euclidean world who, discovering that in experience straight lines apparently parallel often meet, rebuke the lines for not keeping straight – as the only remedy for the unfortunate collisions which are occurring. Yet, in truth, there is no remedy except to throw over the axiom of parallels and to work out a non-Euclidean geometry. Something similar is required in economics. (The deleted sentence reads: "*We require, therefore, to work out a more general theory than the classical theory.*")
>
> (Keynes 1933/1987)

The Grand Crisis that started in fall of 2008 shocked the confidence in market fundamentalism. Fundamental debates on the nature of economic crisis are going back to the Keynesian revolution during the Great Depression. This book of collected essays will address basic issues from five aspects.

Part I is a methodological review on complex evolutionary economics. It includes two review articles. Readers could easily start from there for a basic knowledge in contested issues and competing alternatives.

Chapter 2 on equilibrium illusion, economic complexity, and evolutionary foundation is a review talk on competing methodologies in economic analysis, which was a two-hour invited speech at the Japanese Association for Evolutionary Economics in September 2007, on the eve of the Grand Crisis. This chapter serves as a beginner's guide on major differences between equilibrium and evolutionary perspective, between linear and complex thinking.

There is a widespread misperception that neo-classical economics is imitating classical physics in a frictionless world (Mirowski 1989). This is not quite true. Neo-classical economics did borrow the optimization approach from Hamiltonian mechanics. However, some influential equilibrium models, such as the Frisch model of noise-driven cycles, the Lucas model of rational expectations, and the Coase world of zero transaction costs, simply violate basic laws in physics including the uncertainty principle and the second law in thermodynamics. The role of the FD (first differencing) filter in macro econometrics is similar to that of the geocentric system in astronomy. Mainstream economics felt the fundamental impact of a physics revolution in the 1970s, when discoveries of dissipative structure and deterministic chaos changed the Newtonian paradigm into an evolutionary perspective in physics, chemistry, and biology. The many-body problem is fundamentally different from the one-body and two-body problems in mathematics. That is why methodological individualism and regression analysis is incapable of understanding complex economic dynamics, which is nonlinear and non-integrable in most of cases. This chapter gives a detailed comparison between a linear equilibrium approach and a complex evolutionary approach in micro, macro, finance, and institutional economics, including their policy differences and social outcome in dealing with transition economies and economic crisis. The development from linear Hamiltonian economics to complex evolutionary economics could learn historical lessons from classical mechanics to relativity theory, which is a theoretical progress toward a general theory with a more consistent framework and a wider empirical base (Galbraith 1994).

Chapter 3 is a review article on evolutionary economic dynamics, invited by Kurt Dopfer in his Cambridge volume of Evolutionary Foundation of Economics in 2005, a project started in 1995.

This chapter is a systematic review on evolutionary economic dynamics for readers with more mathematical background. It mainly discusses two basic issues: the endogenous nature of business cycles and diversity trends in social evolution. There are several significant findings in economic theory: the Frisch model of noise-driven cycles in macro econometrics is a perpetual motion machine; the geometric Brownian motion behind the Black–Scholes model in option pricing is explosive in nature; there is a weak microfoundation but a strong meso foundation for generating business cycles. The 1987 model of the division of labor in Chapter 8 was applied to address Adam Smith's dilemma in classical economics and the complexity puzzle in theoretical biology. Evolutionary dynamics has no convergence trend, which is contrary to the claim by the optimization approach. The diversified pattern observed in economic organizations can be explained by a trade-off between stability and complexity under environmental constraints. Market resilience and economic complexity can be better understood by nonlinear population dynamics, which is the pertinent feature for biological and social dynamics.

Part II on macro vitality was our starting base in studying economic complexity. The main issues in business-cycle theory are trend–cycle separation, economic chaos, and persistent cycles.

Chapter 4 on empirical and theoretical evidence of economic chaos in 1988 marked the methodological departure of nonlinear dynamics from econometric analysis. The chapter begins from a brief comparison between linear stochastic and nonlinear deterministic models in a time series analysis. The salient feature of many macro indexes is their growing trend. How to separate long-term trend and business cycles is a critical issue in business-cycle theory. A random image of business cycles is obtained by the FD (first differencing) filter, i.e., the observed variable is the rate of changes in a time unit. The first empirical evidence of low dimensional strange attractors is found in several empirical monetary aggregates by a log-linear detrending (LLD filter). A continuous-time deterministic model with delayed feedback is proposed to describe the monetary growth. Phase transition from periodic to chaotic motion occurs in the model. A one-dimensional nonlinear delay-differential equation is proposed to describe a nonlinear oscillator with soft-boundaries in target control. The soft-bouncing oscillator model is a generalization of hard boundaries, such as the Goodwin limit cycle model with investment floor and ceiling (1951). Time delay and overshooting are the causes of monetary chaos. Chaotic and multi-periodic regions are resilient under shocks in parameter space. This study is the most comprehensive analysis of economic chaos from empirical to theoretical aspects. Its implication in monetary policy is strong evidence of the Austrian theory of endogenous money, but a challenge to Milton Friedman's theory of exogenous money.

Chapter 5 on searching for economic chaos in 1993 was presented at the Austin Symposium in 1989. Methodological differences in testing economic chaos have induced an intensive debate between physicists and econometricians since 1985. Econometricians routinely used a regression analysis to a discrete time model of white chaos such as a logistic or Henon model, while physicists only found empirical evidence of continuous time deterministic color chaos. This chapter demonstrates basic differences between a discrete time and a continuous time chaos model and pitfalls of statistic techniques in testing strange attractors with fractal dimensionality. The role of the time arrow, time scaling, and long-term correlations in econometric testing and modeling is examined. The fundamental problems of econometric inference, modeling, and forecasting in studies of chaotic economic movements are discussed.

Chapter 6 on random walk or color chaos on Wall Street introduced a new method in testing economic chaos by means of time–frequency analysis. The HP (Hodrick–Prescott) filter was suggested by Victor Zarnowicz in Chicago, in addition to FD and LLD filters tested in Chapter 4. The deterministic component from noisy data can be recovered by a time-variant filter in a two-dimensional time–frequency Gabor space. The characteristic frequency is calculated from the Wigner decomposed distribution series. The Wigner–Gabor–Qian (WGQ) spectrogram shows a strong capability in revealing complex cycles from noisy and nonstationary time series. It is found that about 70 percent of HP cyclic fluctuations in Standard & Poor stock price indexes, such as the FSPCOM and FSDXP monthly series can be explained by deterministic color chaos. The characteristic period of persistent cycles is around three to four years. Their correlation dimension is about 2.5. The color-chaos model of stock market movements provides a better alternative in business-cycle theory than a white noise model or Brownian motion. Time–frequency analysis is more powerful than nonlinear dynamics algorithms in analyzing short and noisy economic time series. The analytic program of WGQ transform was provided by Shie Qian in Austin.

Chapter 7 on trends, shocks, and persistent cycles in an evolving economy in 1996 gave a systematic report on business-cycle measurement in time–frequency representation. The term of persistent cycles was suggested by Finn Kydland when he was in Austin. The new method in analyzing business cycles developed in Chapter 6 was systematically applied to a wide range of macro aggregate indexes. Competing detrending methods, including the first differencing (FD) and Hodrick–Prescott (HP) filter, are tested with the mixed case of cycles and noise. The FD filter does not produce a consistent picture of business cycles. The HP filter provides a unified reference in explaining business cycles. Discovery of stable characteristic frequencies from wide ranged economic aggregates provides strong evidence of endogenous cycles and valuable information about structural changes. Economic behavior is more like an organism instead of random walks. A remarkable resilience of a market economy can be seen from a frequency stability compared to an amplitude variability of index levels. The role of time scale and preferred reference from economic observation is discussed.

Part III on population dynamics with micro interaction provides a dynamic approach in studying social behavior including learning, communication, and its outcome in market share competition. Micro dynamic models provide fresh insights to collective behavior and culture diversity in social evolution.

Chapter 8 on origin of division of labor and stochastic mechanism of differentiation in 1987 is a short paper with three basic models in micro dynamics and social evolution. The first model introduced a culture factor in risk orientation, which is observed by the remarkable difference between Western and Oriental cultures. Population dynamics of information diffusion and learning competition is developed for modeling division of labor. Its stability condition shows a trade-off between stability and diversity. The second model is a stochastic birth process for multi-staged development. Emergence of multi-humped distribution, a typical feature of far from equilibrium dynamics, is observable from a theoretical model and empirical evidence. The Gaussian-type distribution breaks down during transitions between different birth rates. The third is a thought experiment of bifurcation mechanism in social behavior. It was a response to skeptics, who questioned the relevance of nonlinear dynamics in social science.

Chapter 9 on imitation, learning, and communication in 1991 is a nonlinear stochastic model for social psychology such as sudden changes of fashion or polarized orientation, which is often called animal spirits by Keynes or irrational behavior in behavioral economics. Their probability distribution is a central or U-shaped pattern. The weakness of the Ising model in equilibrium physics is the concept of social temperature, which is hard to define for non-Hamiltonian systems. A modified population model with social interaction is developed. Imitation, learning, and communication play important roles in understanding complexity in social behavior including a rapid swing in social modes and market variability. An equilibrium perspective based on a mean-variance approach breaks down for U-shaped or bi-modular distribution, since its mean is least likely and its variance is explosive.

Chapter 10 on Needham's question and China's evolution in 1990 was a historical and philosophical consideration of nonequilibrium social transition in the shadow of the June 4 event in 1989 during China's transition from a command economy to a market economy. Joseph Needham's question of why did capitalism emerge in the West and not in China is discussed. There are other related puzzles, such as the Chaunu–Wallerstein puzzle of why land-rich Europe lacks space while population-heavy China lacks population during the civilization division around the fifteenth century; and why a centralized state emerged in pre-modern China 2000 years ago, but division of labor was hard to develop during China's modernization process. The labor-saving resource-intensive technology developed in Europe and resource-saving labor-intensive agriculture developed in China was shaped by ecological constraints, climate change, and patterns of war. The trade-off between the stability and complexity of socio-ecological systems is studied. The evolutionary perspective of nonequilibrium thermodynamics and nonlinear dynamics is helpful in understanding China's transition and economic reform.

Chapter 11 on China's challenge to economic orthodoxy is a dialogue with American economists on the issue of shock therapy in 1993. From an evolutionary perspective, the Asian experience and China's reform can be considered as a self-organizing process, not an equilibrium process. The success of China's economic reform, contrasted with the difficulties of EEFSU, stems mainly from China's willingness to tolerate decentralized experimentation and a gradual evolution of new institutions, whereas in EEFSU a belief of institutional convergence led to the wholesale importation of foreign institutions. This contrast highlights the advantages of a nonlinear nonequilibrium paradigm in evolutionary economics over a linear equilibrium paradigm in neo-classical economics.

Part IV on meso foundation and equilibrium illusions discusses the source of business cycles and false beliefs in equilibrium theories, such as the perpetual motion machine, representative agents, and the driving force of institutional changes.

Chapter 12 on the Frisch model of business cycles in 1999 was a first examination of the theoretical foundation in equilibrium economics. Surprisingly, the most influential model in business-cycle theory and macro econometrics was a spurious doctrine, but a mysterious success, which shared the first Nobel Prize in economics. Frisch once claimed that persistent cycles could be maintained by external shocks, but never formally published its analytical proof. Physicists had already proved that a harmonic oscillator under Brownian motion would quickly cease its harmonic oscillation. An empirical study of US real GDP cycles further reveal that the linear stochastic model is not capable of explaining observed persistent cycles. Theoretically, the Frisch model is a perpetual motion machine, which violates the law of thermodynamics. Persistent business cycles can only be generated by nonlinear economic dynamics. This paper was rejected by a mainstream economic journal, but its main findings were disclosed in Chapter 3.

Chapter 13 on microfoundations of macroeconomic fluctuations and the laws of probability theory in 2002 was a major breakthrough in challenging the new classical macroeconomics, a counter Keynesian revolution led by Robert Lucas in 1972. We found that there was weak evidence of microfoundations in business-cycle theory based on the Principle of Large Numbers and rational expectations were self-defeating under a rational expectations arbitrage. The magnitude of aggregate fluctuations is reversely proportional to the square root of N, the number of micro agents. This relation can be extended to a population model of the birth–death process. The observed orders of fluctuations in the US economy are so large, that there is a weak possibility of microfoundations, but a strong possibility of meso foundations of business cycles. The difference between one-body and many-body problems is critical in theoretical analysis. The Lucas island economy model is a disguised model of a representative agent in nature. Lucas ignored the relative price movements and arbitrage opportunity if micro agents would have independent freedom to make an inter-temporal substitution between work and leisure under rational expectations. Economic structure is not a two-layer but a three-layer system with micro-meso-macro structure. The concept of rational expectations implies infinite information without costing infinite energy, which violates the uncertainty principle in quantum mechanics.

Chapter 14 on complexity of transaction costs in 2007 raised serious question to the Coase theory of transaction costs and proposed an evolutionary perspective in the study of corporate governance. The mechanic picture of transaction costs is rooted in reductionism of firm theory. The Coase world of zero-transaction costs is contrary to the law of thermodynamics and historical trends of increasing energy consumption during industrialization. Its policy implication is promoting deregulation and defending monopolies. Diversified patterns in corporate governance and corporate culture can be better explained by the creative nature of the firm and life cycles in changing ownership and corporate governance. The selective mechanism is more essential to the survival mechanism of a firm than a static judgment of transaction costs.

Part V on market instability, natural experiments, and government policy analyzes two natural experiments, the transition depression in EEFSU in the 1990s and the ongoing Grand Crisis, for testing competing economic theories and policies.

Chapter 15 on market instability and economic complexity in 2006 discussed theoretical lessons from transition experiments. The “Washington consensuses” or “‘shock therapy” simply ignored the Keynesian lessons from the Great Depression. The severe output decline in EEFSU resulted from an equilibrium strategy of liberalization and privatization, which ignored economic complexities and multiple equilibriums under alternative divisions of labor. China’s success of decentralized experiments under a dual-track price system demonstrates the strength of an evolutionary perspective in economic policy. The tremendous cost of the Transition Depression sheds new light on theoretical limitations of equilibrium thinking in neo-classical economics.

Chapter 16 is a talk on reforming the international financial market in July

2009, which called a shift from an old belief in an efficient market to a new perspective of a viable market. Three observations reveal where the equilibrium theory of asset pricing and business cycles went wrong: the meso foundation of macro fluctuations, the endogenous nature of persistent cycles, and the trend collapse and higher moment risk in the derivatives market. A new international financial order can be achieved if a robust international antitrust law is developed and a Tobin tax on foreign exchange transactions can be established through global efforts. An overhaul of financial theory is needed to develop a viable financial market to support sustainable economies.

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.

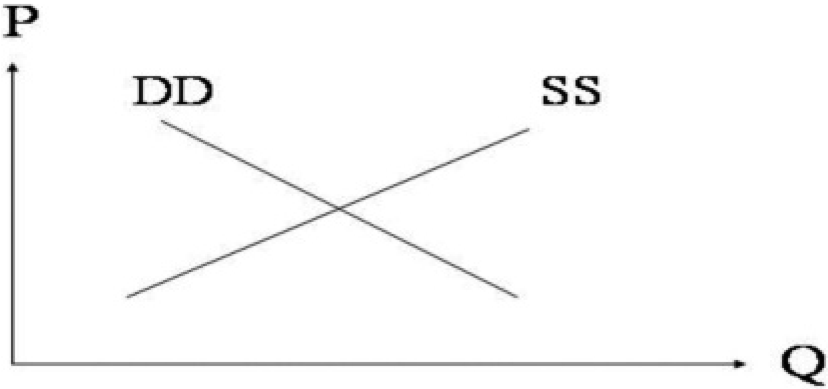
There are three basic models for portrait in self-stabilizing market: the static linear supply–demand curves; the optimization model with convex utility and production functions; and the linear stochastic model of random walk and geometric Brownian motion.

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.

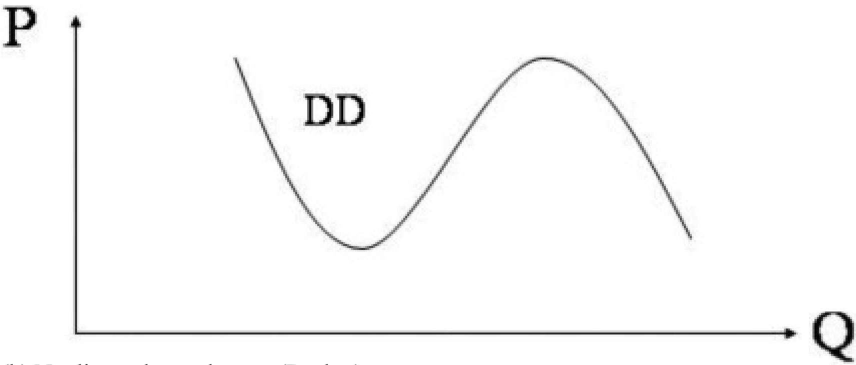
2.3.1.1 The unique equilibrium in linear demand and supply curves

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).

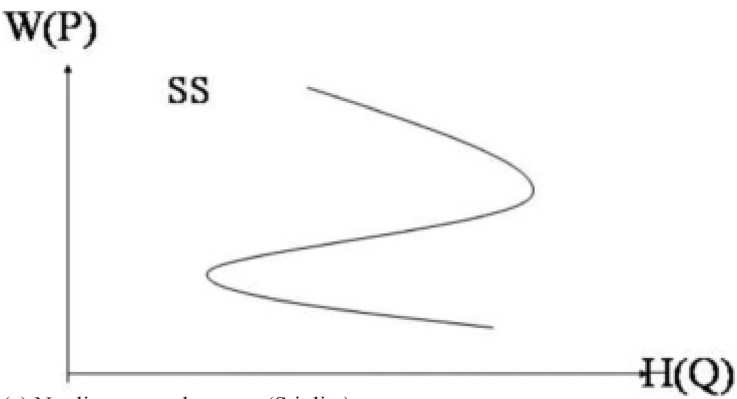
It was known that multiple equilibriums exist under nonlinear demand and supply curves. Social interactions (such as fashion and collective behavior among economic agents, Chen 1991) introduce an S-shaped demand curve (Figure 2.1b, Becker 1991). Nonlinear limitations (such as the subsistence threshold 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

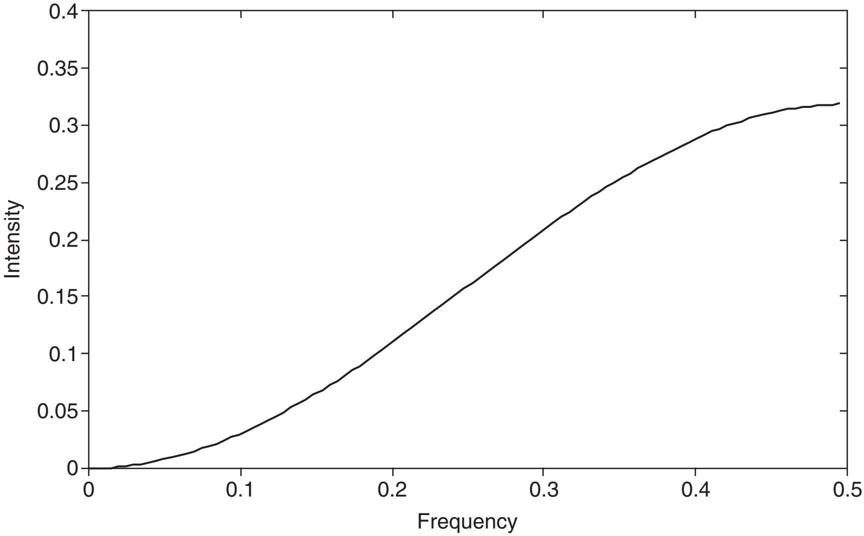


Figure 2.2 Frequency response function for the FD filter.

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

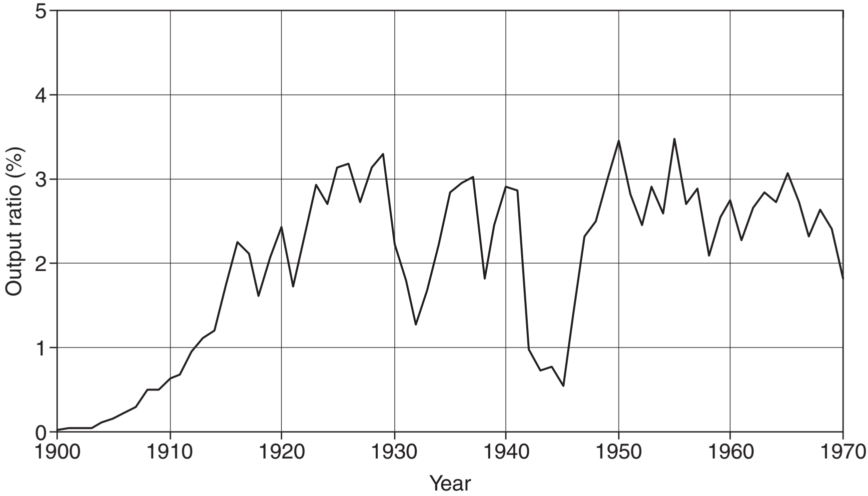


Figure 2.3 The logistic curve of the US automobile industry (source: Carter *et al.* 1997).

Note
Its output is measured by the ratio to GDP.

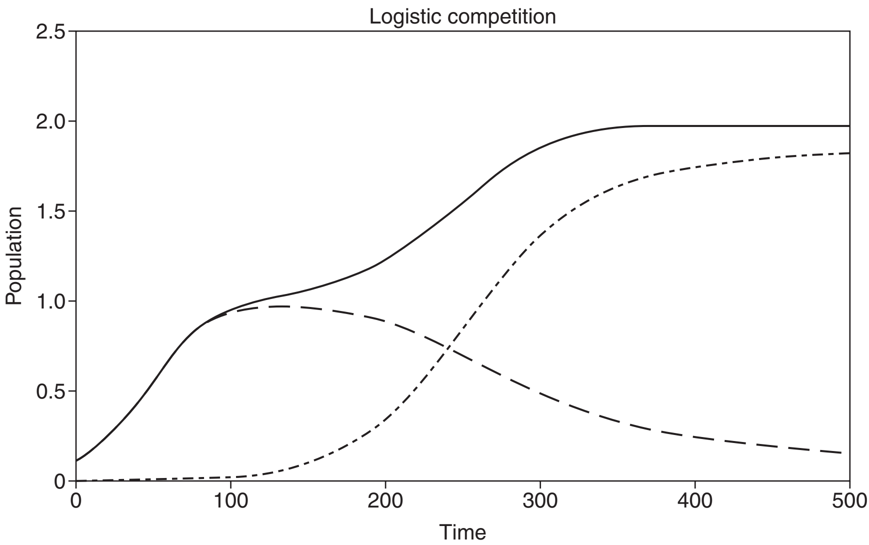


Figure 2.4 The rise of new technology and fall of old technology/industry under competition for limited resources and markets.

"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

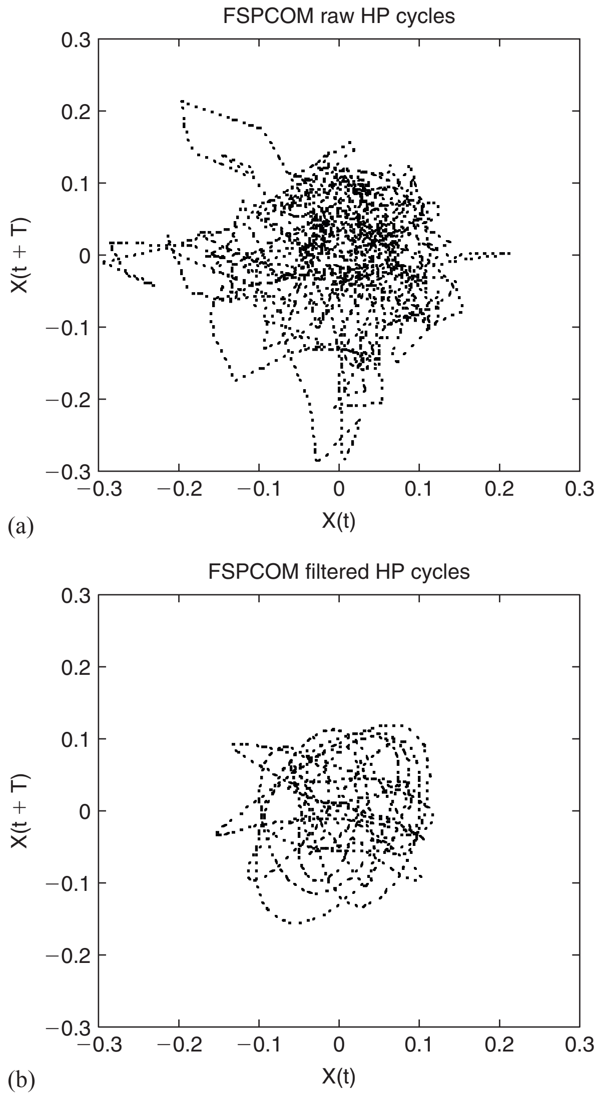


Figure 2.5 The phase portraits of the FSPCOM HP cycles.

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

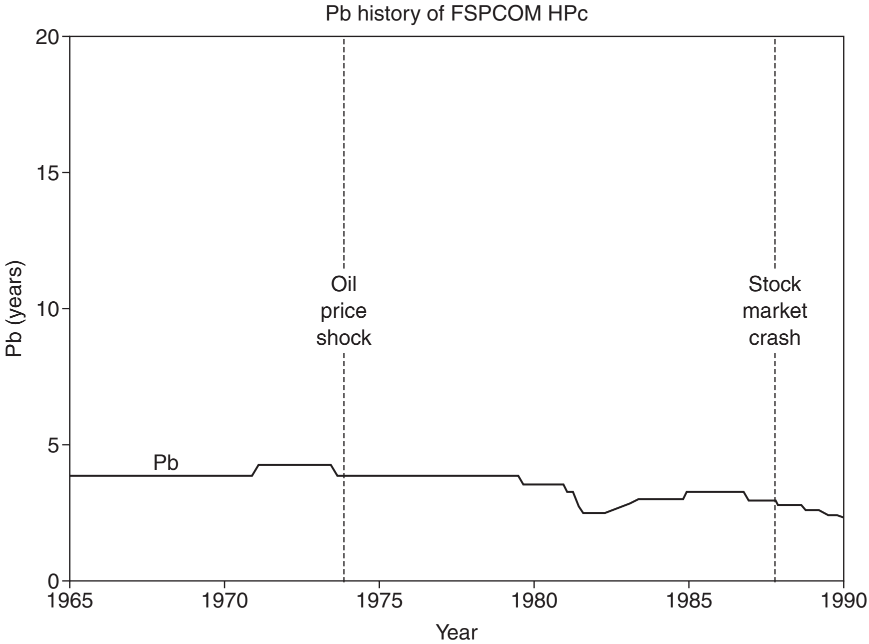


Figure 2.6 The time path of the basic period Pb of FSPCOMln (the S&P 500 stock price index logarithmic series) HP cycles.

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.

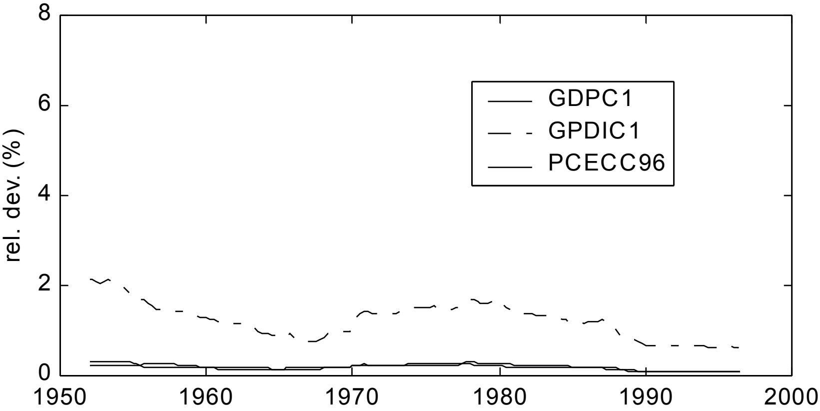


Figure 2.7 The RDs of US aggregate indexes.

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.

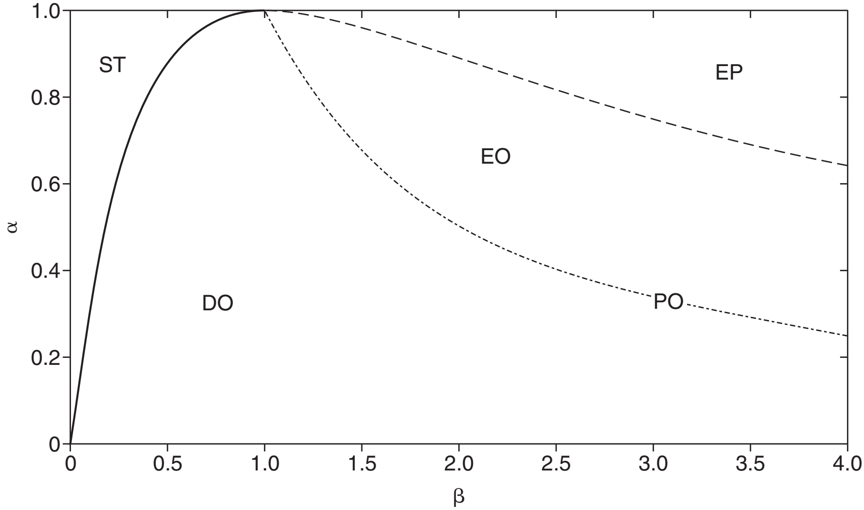
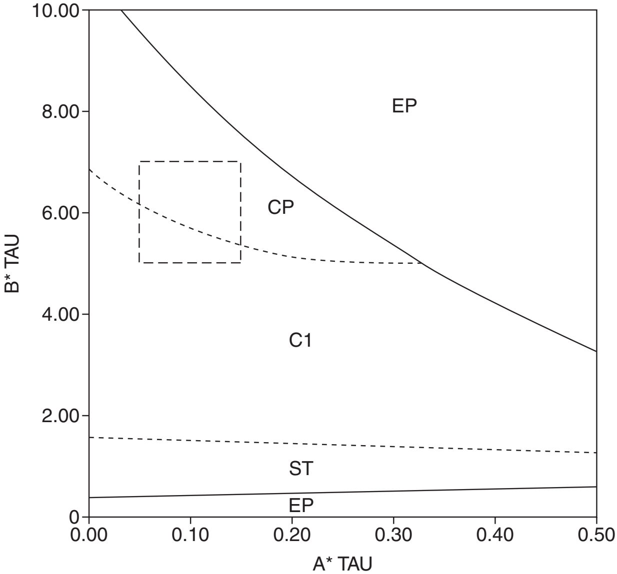


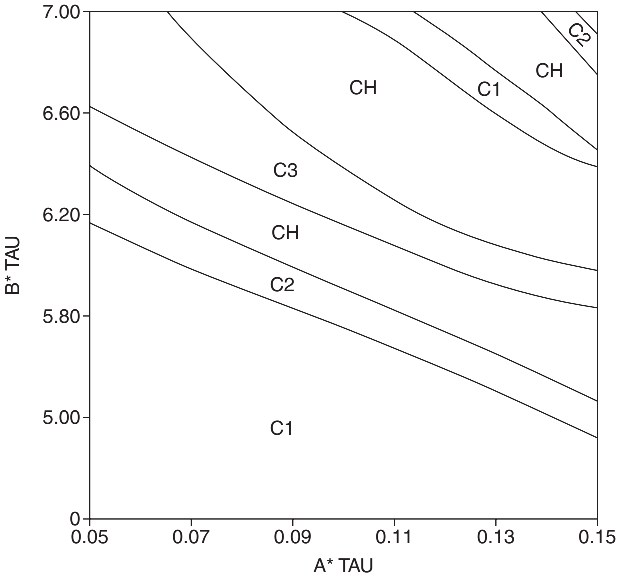
Figure 2.8 Stability pattern of the Samuelson model in parameter space (Samuelson 1939).

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).

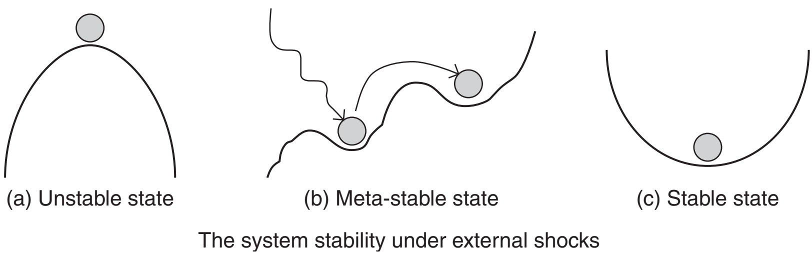


Figure 2.10 Three types of system stability.

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).

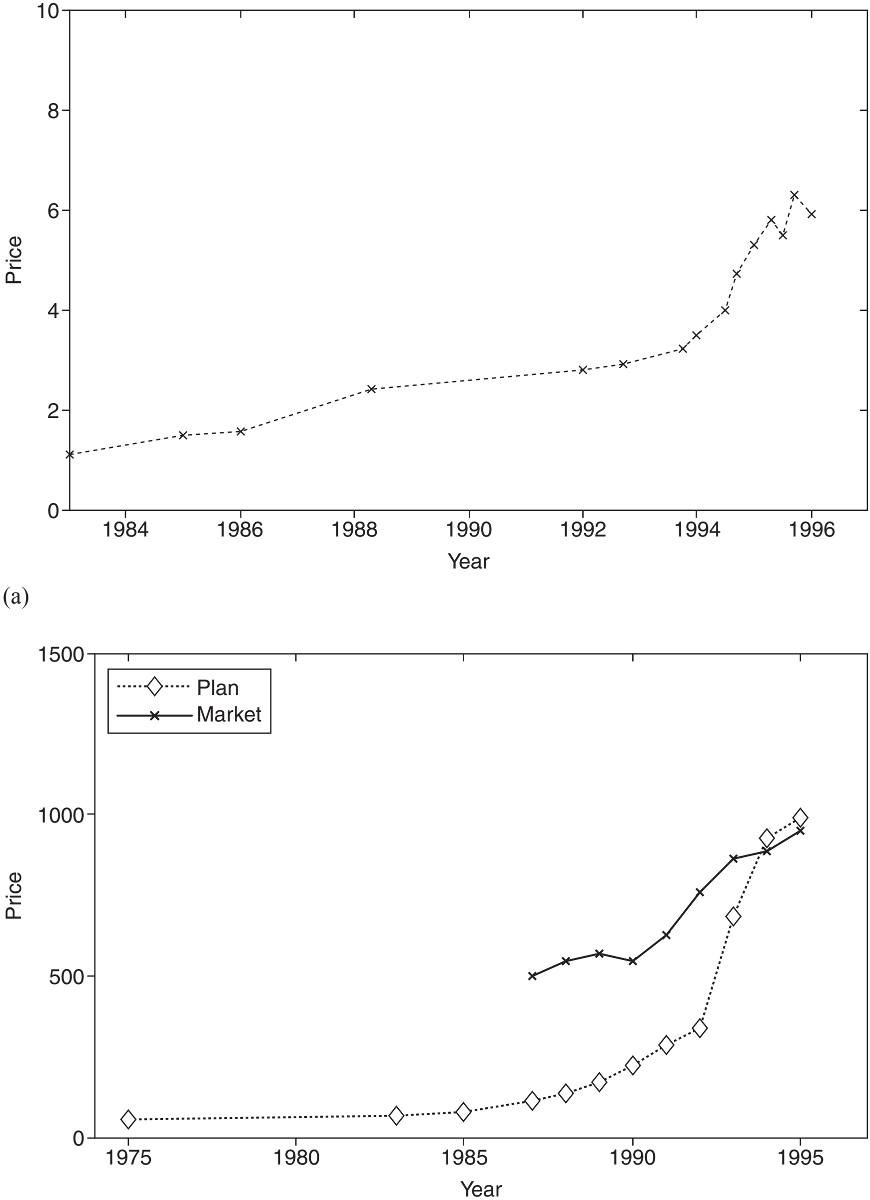


Figure 2.11 Price history in China's Shanghai local market. (a) Fresh pork price in the retail market (1983–1995) (RMB/500g). (b) Heavy oil dual-track price in the industrial market (1975–1995) (RMB/1000 ton).

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.

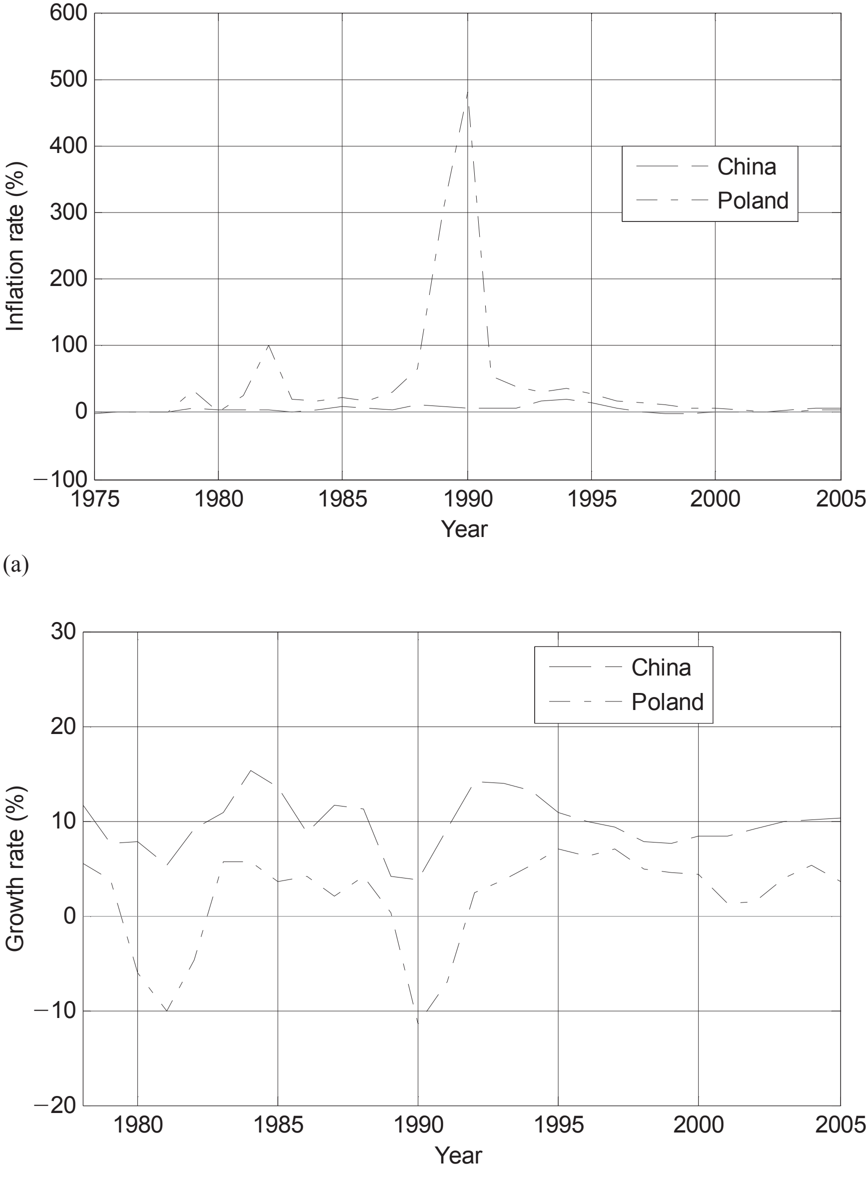
From Chinese historical experience, shortage results from insufficient supply constrained by resource and productivity. Therefore, China's economic reform started with technology imports in the industrial sector and an incentive mechanism (in the form of a family contract system) in the rural sector. 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.



(a)

(b)

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).

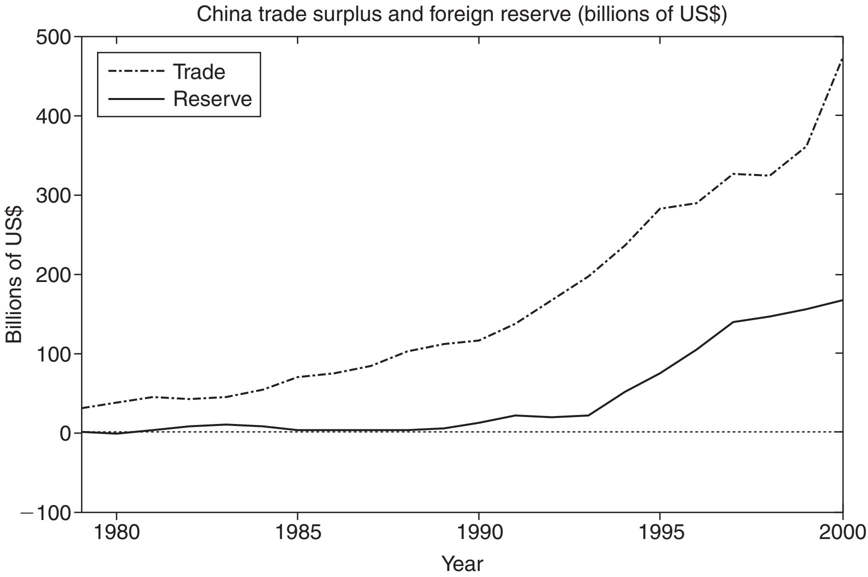


Figure 2.13 China's trade surplus and foreign reserves (source: China Statistics 2001).

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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3 Evolutionary economic dynamics

Persistent cycles, disruptive technology, and the trade-off between stability and complexity[1]

3.1 Introduction: bridge the gap between economics and biology

Alfred Marshall once remarked that economics should be considered closer to biology than mechanics (Marshall 1920). Living systems have two essential features: life rhythms, and the birth–death process. However, the current economic framework is far from Marshall's dream: economic order is widely formulated by a steady-state solution plus random noise. Can we bridge the gap between equilibrium economics and evolutionary biology?

There are two fundamental problems in theoretical economics: the nature of persistent business cycles and the diversity in developing the division of labor. To study these problems, there are two different perspectives in economic dynamics: the equilibrium-mechanical approach and the evolution-biological approach.

The existence of persistent business cycles and chronic excess capacity is hard to explain by using equilibrium models in macro econometrics: external noise cannot maintain persistent cycles in the Frisch model (Chen 1999); aggregate fluctuations in the Lucas microfoundations model are too weak for generating large macro fluctuations according to the Principle of Large Numbers (Lucas 1972; Chen 2002); random walk and Brownian motion are not capable of explaining persistent fluctuations in macro indicators (Chen 2001). Adam Smith once observed that the division of labor was limited by the extent of the market (Smith 1776). Stigler noted that the above Smith theorem was not compatible with the Smith theory of "the invisible hand" (Stigler 1951). Needham asked why capitalism and science originated in Western Europe not in China or other civilizations (Needham 1954). Diversified patterns in the division of labor and corporate strategies cannot be explained within the equilibrium framework.

In our analysis, the time scale plays a key role in understanding economic dynamics. The birth–death process is the first approximation of growth fluctuations. Business cycles can be further decomposed into a smooth trend, plus color chaos and white noise. Persistent cycles and structural changes can be directly observed from a time–frequency representation. Market-share competition and disruptive changes in technology can be described by the logistic model with resource constraint. Innovative corporate strategies can be studied from a behavioral model of risk culture and learning by trying. Logistic curves and product cycles can be inferred from marketing strategy and technological progress. Division of labor is limited by the market extent, resource variety, and environmental uncertainty. The Smith dilemma can be solved by the trade-off between stability and complexity (Chen 1987a). Resilient market and economic complexity can be understood from persistent business cycles and technological metabolism. Economic evolution and structural changes can be directly observed from a wide range of time scales, including product cycles, business cycles, and Kondratieff long waves.

3.2 Endogenous fluctuations and statistical nature in macro dynamics: from equilibrium noise to persistent cycles

The nature of business cycles is an unsolved issue in macroeconomics. There are two schools of thought in business-cycle theory: the exogenous-shocks-equilibrium school and the endogenous-cycles-disequilibrium school.

The exogenous school has four pillar models: the Frisch model of a noise-driven damped oscillator, the Lucas microfoundations model of rational expectations, the random walk, and the Brownian motion model in macro and finance theory (Frisch 1933; Lucas 1981; Nelson and Plosser 1982; Black and Scholes 1973). Endogenous cycles are represented by deterministic oscillators including harmonic cycle, limit cycle, and color chaos (Samuelson 1939; Goodwin 1951; Chen 1988a).

In this section, we will show that equilibrium models are not capable of explaining large fluctuations and persistent cycles in macro movements. The thought experiments that argue against the existence of economic chaos have fundamental flaws in theoretical thinking. The birth–death process and color-chaos model provide a better picture of market resilience and the economic clock observed from business cycles.

3.2.1 The Copernicus problem in macro econometrics: linear and nonlinear trends in macroeconomic indexes

The nonstationary feature of economic growth imposes a great challenge to theoretical economics and economic physics: how to identify some stable patterns from an evolving economy. Can we simplify the observed complex movements into some simple patterns by means of mathematical mapping? This is the Copernicus problem in macro econometrics. The time scale plays a critical role in observing business cycles.

Measurement and theory cannot be separated from each other. The dynamic patterns from competing observation references can be seen in Figure 3.1.

In econometrics, the linear filter of first differencing (FD) is widely applied to construct an equilibrium (short-term) picture of economic fluctuations. The resulting time series are erratic and short-correlated (Figure 3.1b). The random

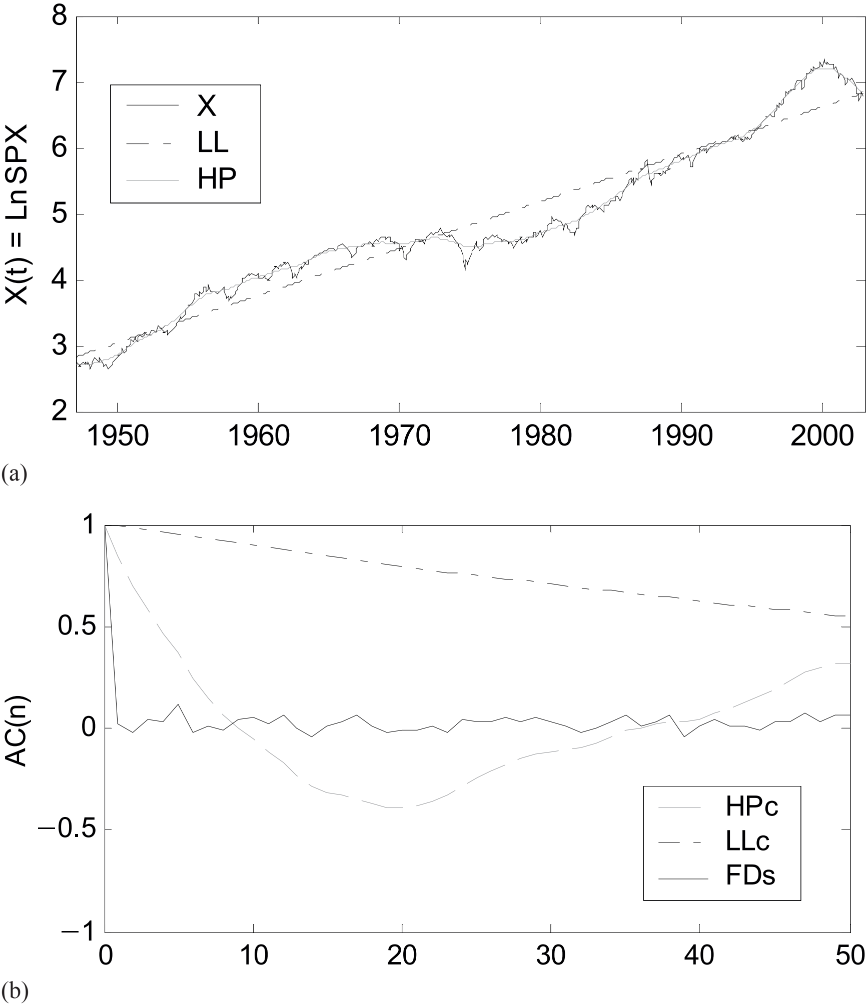


Figure 3.1 Three detrending references and their autocorrelations of detrended cycles from the logarithmic SPX (Standard & Poor's 500 price index monthly series) (1947–2002) (source: http://yahoo.finance). (a) The HP trend and LL trend of X(t), the logarithmic S&P time series. (b) Autocorrelations of detrended cycles, including HPc cycles, LLc cycles, and FDs series.

Note
N = 672.

walk model with a constant drift is also called the unit-root model in macro econometrics (Nelson and Plosser 1982). In neo-classical growth theory, the long-term equilibrium path is characterized by an exponential growth or a log-linear (LL) trend (Solow 1956). The resulting cycles are long-correlated. The problem is that measurement is sensitive to the choice of time boundaries.

An intermediate trend between FD and LL is a nonlinear smooth-trend obtained by the HP (Hodrick–Prescott) filter in the real business-cycle (RBC) literature (Hodrick and Prescott 1997).[2] Its correlation time is in the range of NBER business cycles of several years (Chen 1996b). We will show that the HP trend is better than the other two in giving a consistent picture of medium-term business cycles. This finding reveals the critical role of the time scale in choosing a preferred reference system.

From Figure 3.1b, we can see that the short correlations of FD series look random but HP cycles have an image of damped cycles, which could be generated by color noise or color chaos. Color means a characteristic frequency from the observed fluctuations. The observed variances also depend on the choice of the observation reference trend: the longer the time window, the larger the variance. The LL indicates the largest time window of the entire observational period. The FD implies the shortest time window of one time unit when macroeconomic trends are completely ignored. FD is the root of equilibrium illusion in macro econometrics. The HP implies a medium time window in the range of business cycles.

3.2.2 Equilibrium illusion in business-cycle theory: the challenge of large and persistent fluctuations

The four pillar models in equilibrium theory of business cycles have analytical solutions, which have fundamental difficulties in understanding persistent business cycles. The popular belief in an efficient market would be in trouble when economic complexity exists.

3.2.2.1 The Frisch fantasy of noise-driven cycles: a perpetual motion machine of the second kind?

Frisch realized that the linear model has marginal stability in parameter changes (We will further discuss this issue in section (3.3.3.1)). He speculated that persistent cycles could be maintained by a stream of random shocks. He claimed this scenario in an informal conference paper (Frisch 1933). Equilibrium economists quickly embraced the Frisch model because the stable nature of a market economy could be preserved by a damped harmonic oscillator with friction. However, the Frisch speculation was rejected by physicists in their study of the harmonic Brownian motion, which was solved analytically before Frisch (Uhlenbeck and Ornstein 1930).

The conclusion in physics is contrary to the Frisch fantasy: the harmonic oscillation under Brownian motion will be dampened in an exponential way. Persistent cycles cannot be maintained by random shocks. The relaxation time T_κ and realized period T_r can be estimated from observed autocorrelations (Wang and Unlenbeck 1945):

$$\rho(\tau) = \exp\left(-\frac{\tau}{T_\kappa}\right)\left[\cos\left(\frac{2\pi\tau}{T_r}\right) + \frac{T_r}{2\pi T_\kappa}\sin\left(\frac{2\pi\tau}{T_r}\right)\right]$$

For the Brownian oscillator model of the logarithmic US real GDP, the estimation of relaxation time depends on the choice of the observation reference system. American business cycles would cease within four years for FD or ten years for HP cycles respectively (Chen 1999). The FD reference is worse than the HP reference, since the FD cycles need a large source of external noise, whose standard deviation should be 30 percent larger than the standard deviation of the US real GDP. Since the US economy is the largest in the world, we could not identify an external source to drive American business cycles. Clearly, a linear oscillator is not capable of modeling persistent cycles.

Historically, Frisch quietly abandoned his model as early as 1934. Frisch's promised paper, "Changing harmonics studied from the point of view of linear operators and erratic shocks," was advertised three times under the category "papers to appear in early issues" in *Econometrica*, including Issue No. 2, 3, and 4 of Volume I (April, July, and October 1933). The promised paper was never published in *Econometrica* where Frisch himself was the editor of the newly established flagship journal for the Econometric Society. Surprisingly, Frisch never mentioned a word about his prize-winning model in his Nobel speech in 1969 (Frisch 1981).

If Frisch could use random shocks to generate persistent cycles, it implies a perpetual motion machine of the second kind, which violates the second law of thermodynamics.

3.2.2.2 The Lucas issue of microfoundations and the Principle of Large Numbers

The new classical school called for 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 (Lucas 1972, 1981). He simply ignored the essential differences between the one-body/many-body problems.

As a first approximation, we may consider a macro economy as a static system with N identical agents. The macroeconomy can be described by their total output. We assume that fluctuations in a firm's output or a household's working hours follow an identical independent distribution. The mean is μ, the standard deviation is σ. Based on the law of large numbers and the central limit theorem in probability theory, the mean of the aggregate positive output is $N\mu$, while its variance is $N\sigma^2$. Therefore, we can define the relative deviation (RD) by the ratio of the standard deviation to the mean when the mean of positive variables is not zero:[3]

$$\Omega = \frac{\sqrt{VAR[S_N]}}{mean[S_N]} = \frac{C}{\sqrt{N}} \quad \text{where } C = \frac{\sigma}{\mu} \tag{3.1}$$

For a nonstationary process with internal fluctuations, a linear birth–death process for economic growth will generate similar results (Chen 2002). We can define an implied number N*, which can be estimated from the observed macro series:

$$N^* = \frac{1}{\Omega_{macro}{}^2} = \frac{\mu_{macro}{}^2}{\sigma_{macro}{}^2}$$

We can say that the relative deviation for aggregate fluctuations of N statistically independent positive elements is in the order of

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

we call this rule based on the law of large numbers and the central limit theorem the *Principle of Large Numbers*. The relative deviation is a very useful measure for a wide class of systems with a positive range of variables, such as population, output, working hours, and price.

Empirical measurement of the relative deviation depends on the reference system in observing business cycles. Here, the relative deviation is measured by the ratio of the standard deviation of the HP cycles to the mean of the HP trends within a moving time window since the HP reference produces the largest implied numbers, which are compatible with empirical facts (Table 3.1). Other references have even worse results.

The magnitude of the relative deviation of macro indexes is in the range of 0.2 to 1 percent; its implied number is between 200,000 and 6000. How can we associate these figures with the actual numbers in the US economy? According to the U.S. Bureau of Census, there were 81 million households, three million corporations with more than $100,000 in assets, and about 20,000 public companies in 1980. If we compare these numbers with the implied numbers under HP trends, we can see that the observed implied numbers of these macro indexes are several hundred times smaller than household or firm numbers. In another words, the observed relative fluctuations are at least 20 times larger than could be explained by the microfoundations models in labor or producer markets.

There are several implications from comparisons of these numbers.

Table 3.1 The relative deviation and implied number of degrees of freedom for four macro indexes by HP detrending (1947–2000)

Ω (%) [N]*	*GDPC1Ln*	*PCECC96Ln*	*GPDIC1Ln*	*LBMNULn*
HP	0.21[200,000]	0.17[300,000]	1.3[6000]	0.29[100,000]

Note
Here GDPC1 is the US real gross domestic product in 1996 US dollars; PCECC96, the real personal consumption; GPDIC1 the real domestic investment; and LBMNU the hours of non-farm business. The estimates of relative deviations are averages over the period from 1947–2000 with logarithmic data series.

First, *the representative model in the real business-cycle theory is not valid*, since the observed implied numbers are much larger than one.

Second, *fluctuations in households or firms are not capable of explaining large relative deviations in aggregate output, consumption, business hours, or investment.*

Third, financial intermediaries and industrial organizations appear to play a critical role in generating large business fluctuations since the number of large companies and large financial corporations matches the quantitative range required by implied numbers in investment.

A further examination of the Lucas model of inter-temporal substitution between goods and leisure reveals fundamental flaws in equilibrium thinking. In the Lucas island economy, identical agents believe and act in perfect correlation under rational expectations. If these agents have individual freedom of choice, arbitrage activity will eliminate correlations among individual fluctuations. Lucas claimed that government policy was effective only when it was unexpected. Similarly, rational expectations cannot last long if they mislead believers! Diversified choices are driven by conflicting interests rather than a common belief in a competitive but unequal society. *The rational expectations hypothesis suffers the same self-defeating syndrome of macro econometrics under the Lucas critique*. Clearly, the efficient market, rational expectations, and microfoundations theories do not provide a consistent framework for business-cycle theory. They are, in fact, contradictory in explaining large business fluctuations.

3.2.2.3 The endogenous mechanism and statistical property: the birth–death process against the Brownian motion and random walk

In modeling stochastic growth, the exogenous school is based on the drifted diffusion model, which is also called the geometric Brownian motion model in finance theory (Black and Scholes 1973). Two stochastic models of endogenous fluctuations are used in the economic theory of growth and fluctuations: the random walk model and the birth–death process (Nelson and Plosser 1982; Chen 2002). It is widely perceived that the three stochastic models have similar behavior. There is little doubt about the validity of geometric Brownian motion in economic dynamics.

In the previous section, the relative deviation (RD) plays a fundamental role in studying microfoundations. RD is quite stable for observed macro indicators. Here, we further compare the relative deviations for three popular stochastic models of growth and fluctuations. Their analytical results are shown in Table 3.2 (Chen 2001; Li 2002).

From Table 3.2, we can clearly see that both the random walk and the Brownian motion model cannot generate sustained fluctuations: *the random walk is damping* and *the diffusion model is exploding in time*. It is interesting to note that these two models are a representative agent model in nature. The persistent pattern in economic fluctuations could only be explained by the birth–death process, which is a population model of growth and an endogenous model of

Table 3.2 The statistical properties of linear stochastic processes

Order	*Drifted diffusion*	*Birth–death*	*Random walk*
Mean	$\sim\exp(rt)$	$\sim\exp(rt)$	$\sim t$
Variance	$\sim\exp(2rt)\{e^{\sigma^2 t}-1\}$	$\sim e^{rt}(e^{rt}-1)$	$\sim t$
RD	$\sim e^{\frac{\sigma^2}{2}t}\sqrt{(1-e^{-t\sigma^2})}$	$\sim\frac{1}{\sqrt{N_0}}$	$\frac{1}{\sqrt{t}}$

Note
Here, N_0 is the size of initial population of micro agents in the birth–death process and $r > 0$ for economic growth.

fluctuations. This result raises a fundamental challenge to equilibrium models in terms of representative agent and exogenous fluctuations in macroeconomics and finance theory.

3.2.2.4 Monetary neutrality and coordination cost: the Ricardo device, the Loschmidt paradox, and uneven distribution

The Ricardo device is a thought experiment to justify the neutrality of money. Here, thought experiments are named by their authors. The Ricardo device is the 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). Ricardo ignored the redistribution problem in an unequal society. The Ricardo operation implies a legislation of progressive subsidy or regressive taxation, which has no chance of winning in parliamentary politics. The Ricardo device can only work in a primitive economy with an even distribution of wealth.

The Ricardo device in economics is very similar to the Loschmidt reversibility paradox for challenging Boltzmann's H theorem of thermodynamic irreversibility. Loschmidt argued that one should be able to return to any initial state by merely reversing all molecules' velocity under Newton's law. The trouble here is the huge coordination costs. As noted by Boltzmann in 1877, the possibility of reversing all the initial conditions is very unlikely in dealing with a large system with many particles (Brush 1983). The empirical and theoretical evidence of monetary chaos is a challenge to the neutrality of money (Barnett and Chen 1988; Chen 1988a). Our finding may revitalize the Austrian theory of endogenous money.

3.2.2.5 The rational arbitrager and non-replicate patterns: Friedman spirits, the Maxwell demon, and information ambiguity

Friedman spirits are rational arbitrageurs who wipe out any destabilizing traders on a speculative market (Friedman 1953a, b). The implication is that no structures can exist in a competitive market, which is the main argument for the efficient market hypothesis.

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 only allow a fast molecule into a designated portion by opening or closing the mass-less valve in perfect timing. Therefore, by utilizing information in a smart way, the Maxwell demon could create a temperature difference without doing work,[4] that outcome is contrary to the second law of thermodynamics. No information cost is essential for its operation.

Friedman spirits face a similar problem to the Maxwell demon but in an opposite situation. To eliminate any market instability, Friedman spirits need perfect information and unlimited resources. However, informationally efficient markets are impossible because of the information cost (Grossman and Stiglitz 1980). Under financial constraints, the Friedman spirits may give up negative feedback strategy by following the mass psychology to avoid arbitrage risk, which results in creating instability (De Long *et al.* 1990).

There is an even greater problem of information ambiguity. Friedman assumed that a winner's imitator could quickly replicate the winning pattern and drive down the profit margin to zero. This scenario could be true only if the destabilizing pattern were replicable. This is unlikely because of imperfect information (having only finite data with significant noise and time delays), information ambivalence (in face of conflicting news and mis-information), unpredictable events (such as a financial crisis and changing structure), and limited predictability (existence of deterministic chaos or wavelet). The critical issue of information ambiguity is not only associated with bounded rationality but also rooted in dynamical complexity (Simon 1957; Chen 1993a).

3.2.3 Living rhythms and economic organisms: color chaos vs. white noise

The controversy of noise vs. chaos reveals the limitations of numerical tests in parametric econometrics and nonlinear dynamics (Chen 1988a, 1993a; Brock and Sayers 1988; Benhabib 1992). Testing deterministic chaos in a nonstationary economic time series is more difficult than that of stationary data in laboratory experiments. Conventional econometrics could detect nonlinearity but not chaos. The critical issue here is finding a proper representation in dealing with a nonstationary economic time series.

In this section, we will introduce the Wigner transform in Gabor space for separating noise and cycles. We found abundant evidence of color chaos, which is similar to a biological clock.

3.2.3.1 The uncertainty principle and the Gabor wavelet

The uncertainty principle[5] in time and frequency is the very foundation of signal processing:

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

Here, f is the frequency and t is time. Minimum uncertainty occurs for a harmonic wave modulated by a Gaussian envelope, which is called the Gabor wavelet in signal processing or a coherent state in quantum mechanics. This is the very foundation of time–frequency analysis in the two-dimensional time–frequency Gabor space.

3.2.3.2 Separating noise and cycles in time–frequency space

For analyzing a time-dependent series, we introduced a new analytic tool, the joint time–frequency analysis (Qian and Chen 1996; Chen 1996a, b). A time-varying filter in a two-dimensional time–frequency lattice space can be applied for separating cycles and noise. Its localized bases are the Gabor wavelets. The filtered and unfiltered HP cycles are shown in Figure 3.2. The deterministic pattern of filtered HP cycles can be clearly seen from the phase portrait in Figure 3.3.

The phase portrait of filtered FSPCOM HP cycles shows a clear pattern of deterministic spirals, a typical feature of color chaos. Color chaos here refers to

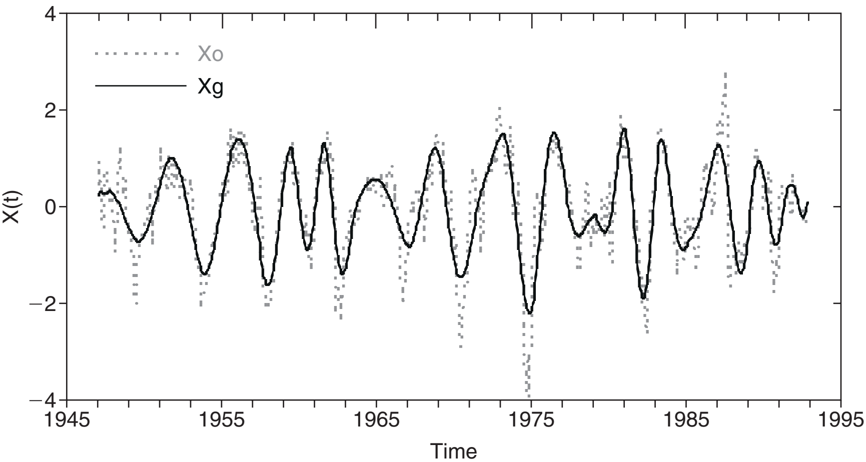
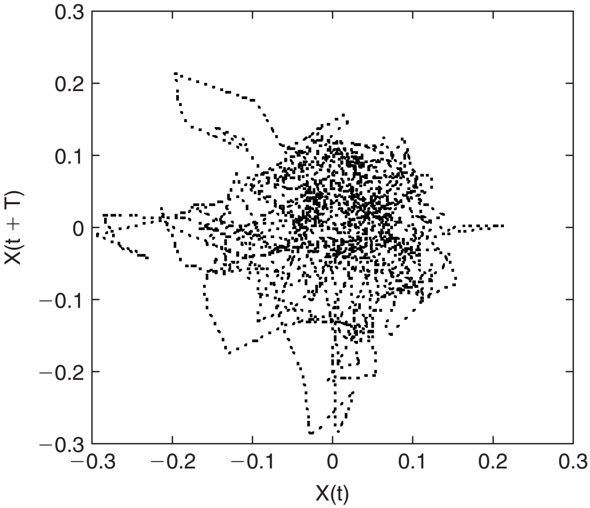
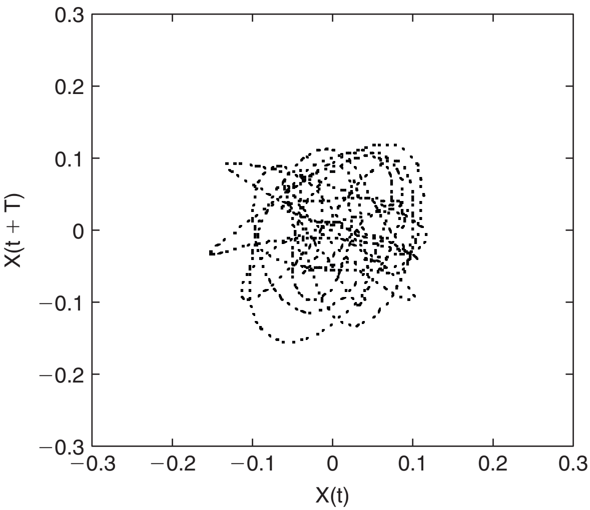


Figure 3.2 The unfiltered and filtered FSPCOM (S&P 500 index) HPc (source: Citibase).

Notes
Xo are unfiltered HPc, Xg are filtered HPc by means of WGQ transform. You may see how Xg closely resembles the original time series Xo. The correlation coefficient between Xg and Xo is 0.85. The ratio of their variance is 69 percent. The correlation dimension of Xg is 2.5.



(a)



(b)

Figure 3.3 The phase portraits of the unfiltered (a) and the filtered (b) FSPCOM HPc.

Note
The time delay T is 60 months. The complex spiral pattern in (b) signals a deterministic chaos in continuous time, i.e., color chaos (Chen 1996a).

the nonlinear oscillator in continuous time. Color shows a strong peak in Fourier spectrum in addition to a noisy background (Chen 1996a).

3.2.3.3 Natural experiments with an economic clock: intrinsic instabilities and external shocks in evolving economies

According to new classical economists, business cycles are all alike if they are generated by pure stochastic processes (Lucas 1981). From new observations in time–frequency analysis, we find that business cycles are not all alike because of strong deterministic components. The time–frequency patterns of macroeconomic indicators resemble biological organisms with multiple rhythms. The frequency path can reveal valuable information in economic diagnostics and policy studies (Chen 1996a, b).

Our picture of an economic clock is a dramatic contrast with those of a random walk in equilibrium economics. Can we conduct some out-of-sample tests to distinguish these two approaches? Perhaps not, because nonstationarity is the main obstacle to the application of statistics. However, the natural experiments of the oil price shock and the stock market crash demonstrate that time–frequency representation reveals more information than white-noise representation (Figure 3.4).

Our finding of persistent cycles supports the biological view of business cycles (Schumpeter 1939).

In addition to stock market indexes, persistent cycles are widely observed from HP detrended economic aggregate indicators, including the gross domestic product, consumption, domestic investment, long-term interest rates, monetary supply indexes, the velocity of money, the consumer price index, and the unemployment rate (Chen 1996b). The range of their characteristic period is from two to ten years, a common feature of NBER business cycles. The noise component ranges from 20 to 50 percent. Certainly, not all macroeconomic indicators behave like biological clocks. Short-term interest rates and foreign exchange rates are very noisy. This information provides a valuable guide for macroeconomic study.

The frequency stability of economic indicators is remarkable. Surprisingly, market resilience is quite robust since most characteristic frequencies are very stable under external shocks and internal instabilities. The stock market crash in October 1987 led to a 23.1 percent drop in the level of the S&P 500 index in two months, but only a six-percentage shift in its characteristic period.

The existence of persistent cycles within business fluctuations is strong evidence of economic color chaos. We should point out that the term "chaos" has a negative image of disorder. We use the term "*color chaos*" which adds a *life rhythm* to a nonlinear oscillator in continuous time. Color means a characteristic frequency, which is similar to a biological clock. This is a contrast to white noise, which has no characteristic frequency.

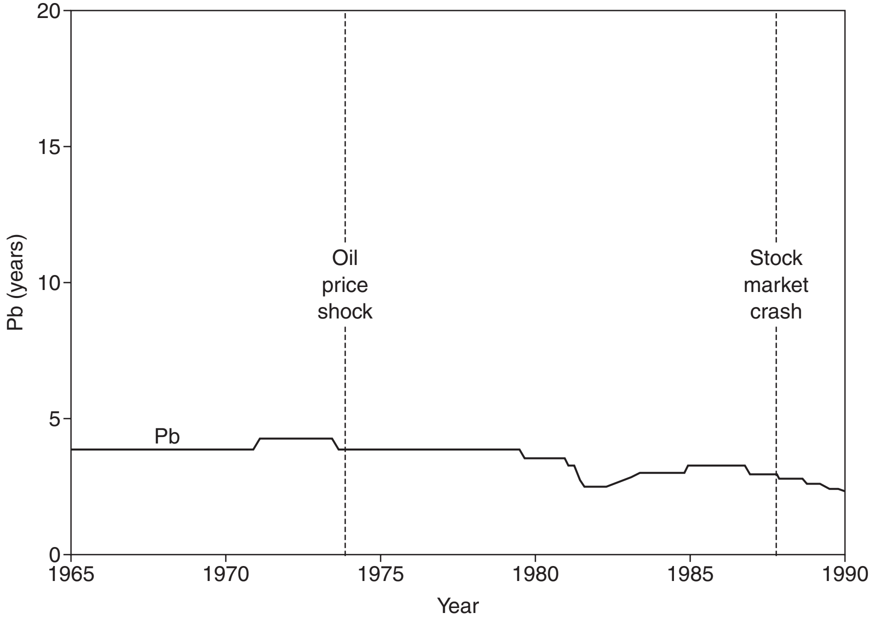


Figure 3.4 The time path of the basic period Pb of FSPCOM (the S&P 500 price index) HPc.

Note
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.

3.2.3.4 Structural instability and market resilience

The structural stability of a market economy is hard to explain within the framework of linear dynamics. This problem can be demonstrated by the Samuelson multiplier-accelerator model (Samuelson 1939). The structural instability of the periodic mode in the Samuelson model can be seen in parameter space (Figure 3.5).

We can see that *the periodic regime PO has only a marginal stability* on the borderline between DO and EO. A small deviation from PO in parameter space will lead to damped or explosive oscillations. *The unit-root model in econometrics has similar marginal stability at the unit circle* (Nelson and Plosser 1982). The problem of structural instability is common for linear models. In the real world, a market economy is very resilient under various shocks.

The problem of structural instability in linear models could be solved by nonlinear models. Consider the example of the soft-bouncing oscillator or "freeway model," which is a mixed difference-differential equation with a targeted floor

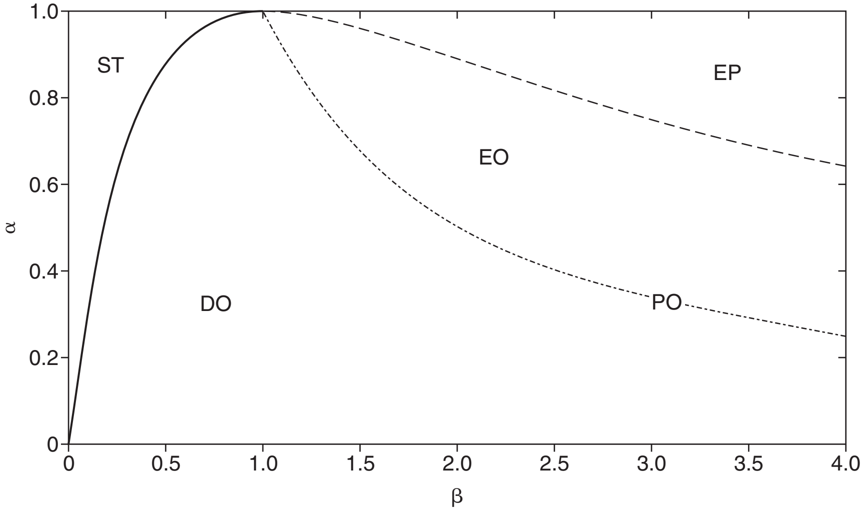


Figure 3.5 The stability pattern of the Samuelson model in parameter space (1939).

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

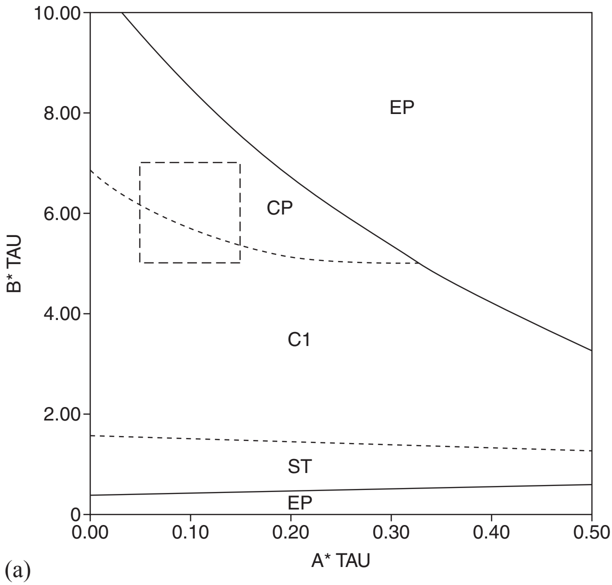
and ceiling (Chen 1988a). Overshooting is caused by time delay in feedback control:

$$\frac{dX(t)}{dt} = aX(t) - bX(t-\tau)\, e^{-[\frac{X(t-\tau)^2}{\sigma^2}]} \tag{3.2}$$

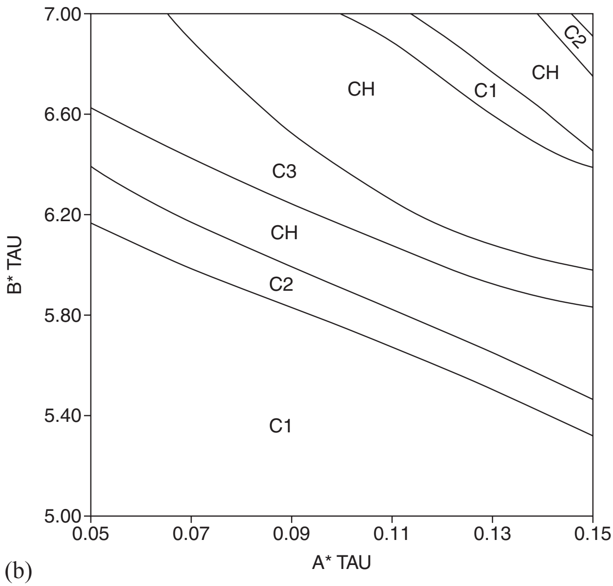
where X is the deviation from the target; τ the time delay; ±σ, the targeted floor and ceiling. The soft nature of control targets is characterized by a non-polynomial control function.

We may consider the left side of equation (3.2) as the rate of change in excess supply, while the right side has a linear supply function but a nonlinear demand function. Soft boundaries can be observed in many economic mechanisms, such as monetary control and the target zone of an exchange rate.

A color-chaos model of the soft-bouncing oscillator has a unified explanation of structural stability and pattern changes (regime switch) (Figure 3.6). Pattern stability can be maintained under external shocks as long as a parameter shift does not cross a regime boundary, since periodic and chaotic regimes have finite measures. A regime switch occurs when an attractor moves into another regime in parameter space. During a regime switch, a small deviation in a parameter may induce a dramatic jump in dynamical patterns. In other words, a quantitative change leads to a qualitative change in such a situation.



(a)



(b)

Figure 3.6 The stability pattern of the soft-bouncing oscillator (equation 3.2) in parameter space (source: Chen 1988a).

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 in (b) is enlarged from the blocked area in (a). You can see alternative zones of limit cycles and chaos in CP regime in (b).

3.3 Market share competition, excess capacity, and creative destruction: behavioral dynamics and the complexity in the division of labor

There is a visible chasm between microeconomic theory and macroeconomic dynamics. In the Arrow–Debreu model in microeconomics, economic order is characterized by a fixed-point solution, while persistent fluctuations are observed in macro dynamics. There is also a culture gap between armchair economics and the business community. There is no room in microeconomics for product cycle, market-share competition, and entrepreneurship, which are core issues in business economics.

Social division of labor can be described by a biological model of species competition (Houthakker 1956). From the previous discussion on the nature of business cycles, we had strong evidence of endogenous fluctuation and intermediate structure. In this section, we will study industrial foundation of business cycles, which is rooted in market-share competition and economic metabolism. In dealing with macroeconomic fluctuations, both Keynesian and new classical economics focus on the demand side, but economic recessions and crises are rooted from excess capacity in the supply side. We will integrate Schumpeter's idea of "creative construction" into Adam Smith's original idea of market extent in the division of labor. The behavioral dynamics based on a generalized population dynamics will shed new light on market-share competition, disruptive technology, the rise and fall of industries or organizations. We may have a new understanding of the Smith dilemma from the perspective of complexity science.

3.3.1 Resource-limited growth and market-share competition: disruptive technology and economic metabolism

Technology advancement is the driving force of industrial economies. The birth and death of technologies and waves of product cycles are common features of a modern economy. Industry competition for increasing market share is largely driven by technology rather than price. The essence of industrial revolution is opening up new resources, not just an efficient utilization of existing resources. The question is how to describe disruptive technology changes in economic dynamics. The production function in neo-classical economics and endogenous growth theory has a fixed parameter for a scale economy, technology innovation is represented by small disturbances (in the form of random noise) in the real business-cycle model; they cannot describe the rise and fall of an industrial technology.

In this section, we introduce the ecological model of market-share competition. The economies of scale and scope are described by the market size in logistic growth and the number of resources available. Product cycles and excess capacity can be understood by co-existence of old and new technologies. The continuous flow of technology wavelets is the ultimate root of uneven growth and business cycles in a macro economy.

3.3.1.1 Logistic growth and dynamic return to scale

In business practice, marginal pricing could not be a winning strategy. Two widely used pricing strategies are cost-plus pricing and strategic pricing (Nagle and Holden 1995). Generally speaking, output and market share for a product will grow when the profit margin for a product is larger than zero:

$$\frac{\partial n}{\partial t} = n\,F(p,c) \tag{3.3a}$$

where n is the output, p the unit price, c the unit cost; the profit margin for a product $F(p, c) = (p - c)$.

If the market extent for the product is N^*, the profit margin must decline to zero when the growth space $(N^* - n)$ shrinks to zero (Zhang 2003):

$$F(p,c) = (p - c) = k(N^* - n) \tag{3.3b}$$

Combine (3.3a) and (3.3b) we have

$$\frac{dn}{dt} = kn(N^* - n)$$

where k is the growth rate.

This is the well-known logistic (Verhelst) equation in theoretical ecology (Pianka 1983). Its solution is an S-curve, which is known in management science (Porter 1980). The market extent N^* can be considered as a function of existing technology, population size, resource limitation, and cost structure. Unlike neo-classic microeconomics, any realistic product or technology has its market extent. Technology advancements are characterized by a sequence of technology shifts. Therefore, technology advancement can be better described by a disruptive change in resource ceiling, rather than a continuous accumulation (Christensen 1997). The key point here is the growth space $(N^* - n)$. As long as there is a growth space, the profit margin will be more than zero, which is true for both monopolies and small firms. This is the essential difference between our approach and neo-classical economics.

For a more general case with birth (growth) rate k and death (exit) rate R, the logistic equation has the general form:

$$\frac{dn}{dt} = f(n) = kn(N - n) - Rn = kn(N^* - n)$$

$$N^* = N - \frac{R}{k}$$

Clearly, economic competition for market share is similar to biological competition for living niches, where the market extent can be described as the population limit or carrying capacity N.

In a decentralized market, the logistic equation can be applied to technology diffusion or information dynamics (Griliches 1957; Bartholomew 1982). In learning dynamics, n is the number of adopters of new technology or the size of the occupied market, $(N - n)$ is the number of potential adopters or the size of an unoccupied market, k is the learning rate, and R is the removal rate. This perspective would be very useful for later study of culture orientation and corporate strategy.

The logistic curve has a varying degree of dynamic economy of scale. The model has a dynamic increasing return for $f'' > 0$ when $0 < n < 0.5N^*$ and dynamic diminishing return for $f'' < 0$ when $n > 0.5N^*$. For a model of asymmetric growth, the reflection point may not be the middle point. In contrast, the production function in neo-classical microeconomics has fixed returns to scale. Therefore, the neo-classical theory of firm is not capable of describing economies of scale and market-share competition.

3.3.1.2 Two-species competition and the source of excess capacity

When there are two competing technologies, their market shares are characterized by their resource ceilings N_1 and N_2. The Lotka–Volterra competition equation in population dynamics can be applied to market-share competition under conditions of limited resources (Pianka 1983).

$$\frac{dn_1}{dt} = k_1 n_1 (N_1 - n_1 - \beta n_2) - R_1 n_1 \tag{3.4}$$

$$\frac{dn_2}{dt} = k_2 n_2 (N_2 - n_2 - \beta n_1) - R_2 n_2$$

Where n_1, n_2 are population (or output) of species (technology or product) 1 and species 2; N_1 and N_2 their carrying capacity (or resource limit); k_1 and k_2 their growth (or learning) rate; R_1 and R_2 their removal (or exit) rate; β is the overlapping (or competition) coefficient in resource competition ($0 \le \beta \le 1$). The equations can be simplified by introducing effective carrying capacities

$$C_i = N_i - \frac{R_i}{k_i} .$$

In this model, the essence of price competition is still in the form of market-share competition, since a better quality or cheaper price implies a larger market extent N_i.

When $\beta = 0$, there is no competition between the two species. Both of them can grow to their market limit. A firm or industry without competition could realize its full capacity to occupy the designated market share C.

Species 2 will replace species 1 under the following condition. The winner may have a higher resource capacity, a faster learning rate, or a smaller death rate:

$$\beta\left(N_2 - \frac{R_2}{k_2}\right) = \beta C_2 > C_1 = \left(N_1 - \frac{R_1}{k_1}\right) \tag{3.5}$$

When $0 < \beta < 1$, the two species can co-exist. However, the realized market share would decline for both species:

$$\beta < \frac{C_2}{C_1} < \frac{1}{\beta} \tag{3.6a}$$

$$n_1^* = \frac{C_1 - \beta C_2}{1 - \beta^2} < C_1 \tag{3.6b}$$

$$n_2^* = \frac{C_2 - \beta C_1}{1 - \beta^2} < C_2$$

$$\frac{1}{2}(C_1 + C_2) \leq n_1^* + n_2^* = \frac{(C_1 + C)_2}{1 + \beta} \leq (C_1 + C_2) \tag{3.6c}$$

From equation (3.6c), we find excess capacity may increase up to 50 percent under symmetric technology competition. Excess capacity could be even higher under asymmetric competition. Now, we may solve the puzzle observed in section (3.2.2.2): why is investment fluctuation much larger than that in GDP and consumption? *The excess capacity is caused by co-existence of old and new technology*, not just a speculator's psychology (so-called "animal spirit" by Keynes).

A striking fact is that the chronic excess capacity in US industry persists on a level of about 18 percent, which is hard to understand by optimization theory (Hall 1986). We may calculate β for two empirical cases. β is 0.22 for 18 percent excess capacity in the US, and 0.52 for the 36 percent excess capacity for China in 1995. The excess capacity can be a measure for Schumpeter's "creative destruction."

3.3.1.3 The Lotka-Volterra wavelet and the stages of economic growth

A numerical solution of equation (3.4) is shown in Figure 3.7. Without competition, the growth path of species 1 would be an S-curve. However, the realized output of technology 1 looks like an asymmetric bell curve. This feature represents a product cycle in marketing and management literature (Moore 1995). We call it the Lotka–Volterra (LV) wavelet, which is a result from the competition of technology 2. The envelope of the aggregate output has both growth trends and cycles that mimic the pattern of a macroeconomic index. Now, we understand why persistent business cycles are well portrayed by time–frequency representation, since the asymmetric Bell curve is close to the shape of a bell curve.

We may characterize industrial revolution as a higher resource ceiling or a larger market extent. Seemingly continuous growth can be decomposed into a

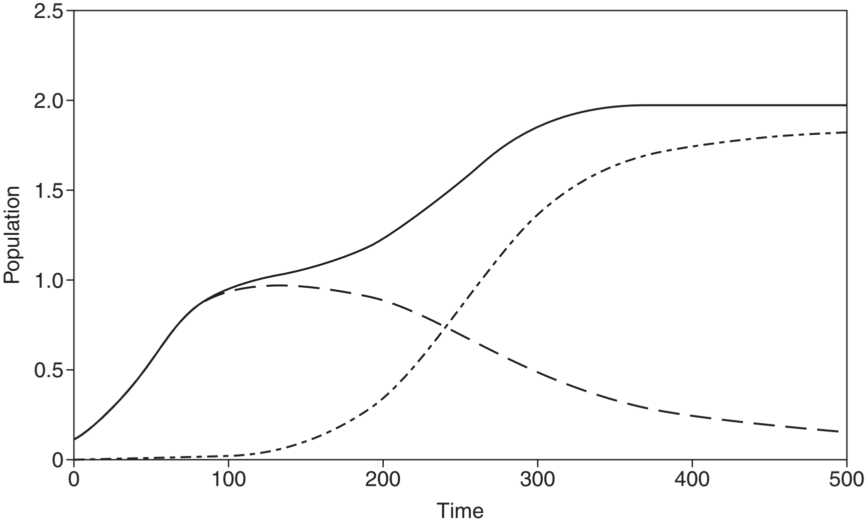


Figure 3.7 Staged economic growth characterized by dynamic path of equation (3.2).

Notes
The output envelope is the sum of competing species. Here, $\beta = 0.4$, $C_2/C_1 = 2$. The units here are chosen for stylized fact.

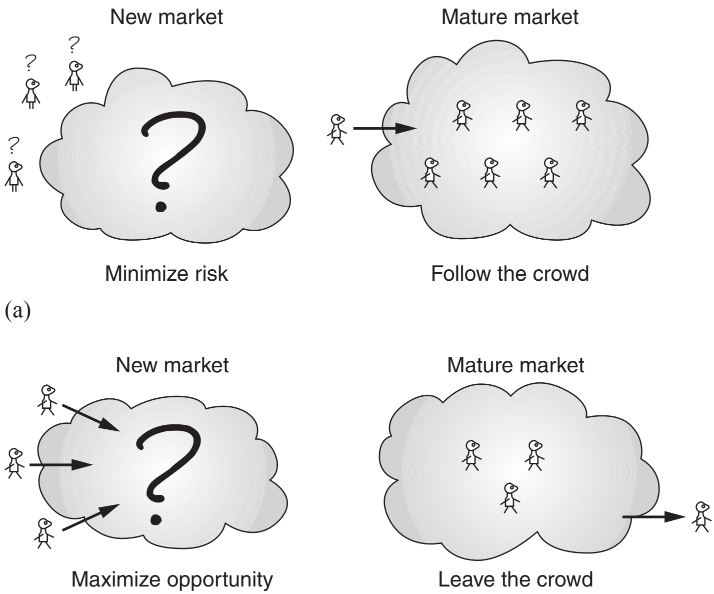
sequence of staged growth or disruptive changes in technology advancement (Rostow 1990; Christensen 1997). The time scale of a LV wavelet varies from a product cycle of several months to a Kondratieff long wave of several decades, depending on the questions asked in history. Financial crises are often triggered by emerging technology and subsequent bifurcation in investment choice.

3.3.2 The risk attitude and corporate culture in behavioral dynamics

In equilibrium finance theory, the financial risk is characterized by the variance around the mean of returns; rational agents are defined by risk-aversion behavior. In our competition model, we introduce another kind of risk: the risk facing an unknown market or technology. This concept of learning by trying is inspired by Schumpeter's idea on entrepreneurial spirit. Competing corporate cultures are characterized by their risk attitude in facing a challenge or opportunity.

3.3.2.1 Learning by trying: risk-aversion vs. risk-taking behavior

The culture factor plays an important role in decision making and corporate strategy. There is a great variety in the degree of "individualism" or risk-taking among different cultures. Both risk-aversion and risk-taking strategies are observed when competing for an emerging market or new technology (Figure 3.8). From this perspective, knowledge in old technology does come from learning by doing, which



(b)

Figure 3.8 Risk attitude or culture factor in species competition for new market or new resource. (a) Risk-aversion behavior: the conservative strategy for minimizing uncertainty, which is often observed in collective culture. (b) Risk-taking behavior: the contrarian strategy for maximizing opportunity, which is often observed in individualist culture.

is an accumulation process in endogenous growth theory (Arrow 1962). In a new market, knowledge comes from learning by trying, which is a trial and error process in evolutionary economics (Chen 1987a, 1993b).

When facing an unknown market or unproved technology, risk-averting investors often follow the crowd to minimize the risk, while risk-taking investors take the lead to maximize the opportunity. A critical question is: which corporate culture or market strategy can win or survive in a rapidly changing technology or evolving market?

The original logistic equation describes a risk-neutral behavior by assuming a constant removal rate. We introduce a nonlinear removal rate as a function of the learner's population ratio and the behavioral parameter a (Chen 1987a):

$$R\left(r, a, \frac{n}{N}\right) = r\left(1 - a\frac{n}{N}\right)$$

where

$$-1 < a < 1.$$

We may consider the constant r as a measure of the learning ability or degree of difficulty in studying a new technology.

The factor a is a measure of risk orientation. If $a > 0$, it is a measure of risk-aversion or collectivism. When few people enter the new market, the exit rate is large. When more and more people accept the new technology, the exit rate declines. On the contrary, if $a < 0$, it is a measure of risk-taking or individualism. When varying a from minus one to plus one, we have a full spectrum of varying behavior, from an extreme conservatist to an extreme adventurer.

3.3.2.2 Resource-saving and resource-consuming cultures

The equilibrium rate of resource utilization is:

$$\frac{n^*}{N} = \frac{\left(1 - \frac{r}{Nk}\right)}{\left(1 - \frac{ra}{Nk}\right)}$$

$$n^*_{a<0} < n^*_{a=0} < n^*_{a>0}$$

The resource utilization rate of the conservative species ($n^*_{a>0}$) is higher than that of the individualist species ($n^*_{a>0}$). The individualist species needs a larger subsistence space than a conservative one in order to maintain the same equilibrium size n^*. Therefore, individualism is a resource-consuming culture while collectivism is a resource-saving culture (Chen 1990, 1993b). This difference is visible between Western individualism and Oriental tradition. Cultural differences are rooted in economic structures and ecological constraints. Resource expansion is a key to understanding the origin of a capitalist economy and the industrial revolution (Pomeranz 2000).

3.3.2.3 Market extent, resource variety, and economy of scale and scope

In an ecological system with L species, resource capacities are $N_1, N_2, \ldots, N_L$. The economy of scope and scale can be described by a system of coupling logistic-type equations. Here, the market extent is represented by the resource capacity N, while the scope of economies is described by the number of species L. The division of labor can be characterized by the co-existence of competing technologies.

Let's start from the simplest case with only two species with competing technologies and cultures (Chen 1987a):

$$\frac{dn_1}{dt} = k_1 n_1 (N_1 - n_1 - \beta n_2) - r_1 n_1 \left(1 - \frac{a_1 n_1}{N_1}\right) \qquad (3.7)$$

$$\frac{dn_2}{dt} = k_2 n_2 (N_2 - n_2 - \beta n_1) - r_2 n_2 \left(1 - \frac{a_2 n_2}{N_2}\right)$$

Here n_1, n_2 is the new technology adopters in species 1 and species 2 respectively. We also take $\beta = 1$ for simplicity.

3.3.2.4 The latecomer's opportunity and entrepreneur's advantage

We may solve equation (3.7) in the same way in section (3.3.1.2). The replacement condition is:

$$C_2 > \frac{\left(1 - \dfrac{a_2 r_2}{k_2 N_2}\right)}{\beta} C_1 \text{ for species 2 replace species 1.} \tag{3.8}$$

What would happen when an individualist species competes with a conservative one? If two species have equal resources ($N_1 = N_2$), then, the conservative species will replace the individualist one. If we compare (3.8) with (3.5), a latecomer from a conservative culture has a better chance to beat the individualistic leader even if $C_2 \leq C_1$ when $\beta \approx 1$ and $0 < a_2 \approx 1$. This is the story of how the Soviet Union and Japan caught up with the West in the 1950s and 1970s respectively. Conservative culture can concentrate its resources in a "catching-up" game.

Therefore, the only survival strategy for an individualist species in competing with a conservative one is to explore a larger resource or learn faster. If we consider entrepreneurship as a risk-taking culture, then we may reach a similar conclusion to Schumpeter's – creative destruction is vital for capitalism in the competition between socialism (collectivism) and capitalism (individualism). Once innovations fail to discover new and larger resources, the individualist species will lose the game to the conservative in the existing markets.

3.3.2.5 Progressive culture and a pluralistic society

Now, we examine the co-existence condition:

$$\frac{\beta}{\left(1 - \dfrac{a_1 r_1}{k_1 N_1}\right)} < \frac{N_2 - \dfrac{r_2}{k_2}}{N_1 - \dfrac{r_1}{k_1}} < \frac{1}{\beta}\left(1 - \frac{a_2 r_2}{k_2 N_2}\right) \tag{3.9}$$

From this equation, it can be seen that two individualist species may co-exist. Individualism is the root of diversity and democracy in the division of labor and capitalism. However, two conservative species cannot co-exist, the only result is one replaces the other. This is the story of peasant wars and dynastic cycles in Chinese history. Therefore, division of labor cannot emerge in a conservative society, which is a theoretical answer to Needham's question (Needham 1954; Chen 1987a, 1991a).

3.3.2.6 The culture dimension and the thermodynamics of evolution

Max Weber identified the accumulation of capital as the essence of the Protestant and the capitalist culture; he also considered Confucianism as the main barrier to developing a market economy (Weber 1930). We disagree. The rise of Asian tigers and the success of China's reform is strong evidence that the Confucian culture of family values, equal education, and encouraging saving may be a positive factor in developing a market economy. The key difference of China before and after 1979 is its open-door policy and access to the world market. This is the most important lesson the author learned from Prigogine's thermodynamics of evolution (Prigogine *et al.* 1972).

According to Prigogine, there are three types of order: maximum entropy (disorder) in an isolated system is dictated by the second law of thermodynamics where no structure exists; equilibrium structure (such as a crystal) can exist in a closed system where energy is exchanged with the surroundings; nonequilibrium order can only emerge in open systems where a dissipative structure is maintained by continuous energy flow, matter flow, and information flow. Certainly, any living or economic system is an open system by nature. However, the essential pattern in social evolution depends on the degree of openness. The rise of the West is a clear history of resource expansion, first by geographic discovery of the New Continent, then by revolutions in science and technology. In contrast, China's involution was mainly caused by land limitation and technological stagnation (Huang 1985; Chen 1990, 1993b). China did reverse its involution after its access to modern technology and the world market.

3.3.2.7 The number of resources and the competition exclusion principle

From equation (3.6), we have the well-known "competition exclusion principle" in theoretical biology, since complete competitors cannot co-exist. It implies that the number of species should equal the number of resources.

However, the definition of species and division of resources is arbitrary (Pianka 1983). There are similar problems in the theory of complete markets. In other words, the number of prices should be equal to the number of assets in market equilibrium models. Equilibrium in the asset market is defined by the absence of arbitrage opportunity, which implies linear pricing (Ross 1976). In fact, nonlinear pricing is widely observed in the form of volume discount, credit rationing, and strategic pricing that are shaped by market uncertainty, information asymmetry, and scale economy.

Our model overcomes this difficulty. According to equation (3.9), the outcomes of competition also depend on the behavioral factor a_i. Therefore; *the number of species may not be equal to the number of resources.* This may shed light on the mechanism of price differentiation.

3.3.3 The complexity puzzle and the Smith dilemma

There are conflicting perspectives on convergence or divergence issues in division of labor. The neo-classical school believes in market convergence based on optimization and rationality (Yang and Borland 1991; Becker and Murphy 1992). Division of labor could be a divergent process with bifurcation and uncertainty, where multi-humped distributions and path-dependence are rooted in nonlinear interactions (Chen 1987a, 1990; Arthur 1994).

Interestingly, the Smith dilemma in classical economics is related to the complexity puzzle in theoretical ecology and the science of complexity. The question is whether or not increasing complexity is associated with increasing stability. Some biologists believe the correlation is positive. The doctrine of "the survival of the fittest" seems to imply that the fittest must be stable. However, mathematical simulations produced negative correlations. We call this a complexity puzzle (Gardner and Ashby 1970; May 1974a; Chen 1987a).

Contrary to the belief of some biologists and many economists, we suggest that evolution from simplicity to complexity does decrease a system's stability, but it also increases the potential for further development. We call the negative correlation the *trade-off theory between stability and complexity, or the trade-off between security and opportunity.* This trade-off provides a clue to solving the Smith dilemma. We will discuss system stability under environmental shocks.

3.3.3.1 Monolithic society and stability under environmental shocks

Let us start from a single species. By means of the Langevin equation and Fokker-Planck equation, we may consider a stream of random shocks adding to the carrying capacity (market extent) N. The realized equilibrium size X_m is reduced by a fluctuating environment, which is described by the variance of shocks:

$$X_m = N\frac{\left(1-\dfrac{r}{kN}-\dfrac{k\sigma^2}{2N}\right)}{\left(1-\dfrac{ra}{kN}\right)} \qquad \text{when } \sigma < \sigma_c = \sqrt{\frac{2N}{k}\left(1-\frac{r}{kN}\right)}$$

$$X_m = 0 \qquad \text{when } \sigma > \sigma_c = \sqrt{\frac{2N}{k}\left(1-\frac{r}{kN}\right)}$$

If there exists some survival threshold in population size, then the conservative species has a better chance of surviving under external shocks because of its larger population size. Obviously, the World Trade Center in New York is more vulnerable to a bombing than a village in Vietnam.

3.3.3.2 The trade-off between stability and complexity and a two-way evolution of division of labor

The Fokker-Planck Equation corresponding to equation (3.7) can be solved numerically. We consider an environmental fluctuation imposed to the carrying capacity N and study its stability condition (May 1974a). The main results are as the following:

First, environmental fluctuations will further reduce the size of the equilibrium state.

Second, the system's stability will decrease as competition between species increases.

Third, if we compare two systems, one is the mixed system with one conservative species and one individualist species, the other is the liberal system with two individualistic species; and then the stability of the mixed system will be larger than the liberal system (Chen 1987a). This result is perceivable when we compare the two-party system in the Anglo-Saxon countries and the multiparty system in continental Europe.

Finally, we can see that the division of labor is a two-way evolutionary process. When environmental fluctuation is within the boundary of the stability condition, the system with more species can survive; when fluctuation is beyond the stability threshold, a complex system may break down into a simpler system with fewer elements. This conclusion is dramatically different from the optimization model of division of labor (Yang and Borland 1991).

3.3.3.3 The generalized Smith theorem: the division of labor is limited by the market extent, resource variety, and environment fluctuations

From the above discussions, we have a new understanding of corporate structure and a comparative advantage in a changing environment. The Smith dilemma indicates a problem since small competitive firms and large monopoly corporations cannot co-exist within the framework of equilibrium economics (Stigler 1951). This is not a problem in evolutionary economics because of the trade-off between stability and complexity.

We propose *a generalized Smith theorem* to integrate new findings from evolutionary dynamics: *the division of labor is limited by the market extent, resource variety, and environment fluctuations*. We discuss its applications below.

Based on the generalized Smith theorem, we can easily explain the rise and fall of great civilizations. The China Empire lasted for more than 2000years, which was much longer than the Roman Empire and the Byzantine Empire. Its structural stability was rooted in self-sufficient grain-based agriculture with underdeveloped division of labor. This system was influenced by severe ecological constraints, cyclic disasters, and large-scale peasant wars. On the other hand, the origin of division of labor and capitalism resulted from resource expansion and moderate fluctuations in the natural and social environment in Western Europe. China's involution towards self-sufficiency was shaped by intensive agriculture under resource limits and severe environment. For example, from the third century BC to the nineteenth century, there were 13 periods of large-scale wars with a population reduction of more than one-third of the Chinese population, but Western Europe faced this type of turbulence only once (the Black Death). The frequency and intensity of ecological crises in China were also much higher than that of Western Europe. The bifurcation point occurred around the thirteenth to fifteenth centuries, when the Black Death stimulated labor-saving innovations and the spice trade motivated geographic discovery and the expansion of a world market. This scenario is a historical answer to Needham's question (Chen 1990).

Some puzzles in transition economies can also be understood from the perspective of complex systems. The collapse of the Soviet economy and success in China's reform are two polar cases in transition economies. An extreme international division of labor characterized the Soviet economy with little redundancy and competition. Once a link in the economic chain was damaged, the entire system in Eastern Europe broke down. On the contrary, China's self-sufficient policy in Mao's era created many potential competitors in regional economies. When China's open-door policy broke the regional protectionism, local firms had to compete in a national and global market. The existence of competing firms is the precondition for a successful program of market liberalization. Sufficient redundancy in a complex system is necessary for its structural stability, which is a valuable lesson for Eastern Europe.

Based on the trade-off between stability and complexity, we also have a new understanding regarding the causes of mergers and breakups. Increasing efficiency and market power is often considered as two main reasons for merger activities in the theory of industrial organization (Carlton and Perloff 1994). We offer a third cause in merger or sell-offs waves, which is based on the trade-off between opportunity and stability. Merger waves generally appear during an economic upturn and end when facing a downturn; corporate restructuring and sell-offs often arise during an economic downturn because large firms are rigid and slow in adapting to technological changes (Weston *et al.* 2003).

3.4 Conclusion: understanding market resilience and economics complexity

Equilibrium economics has not developed a consistent framework of economic dynamics. Microeconomics is a static theory, where there is no room for product cycle, market-share competition, strategic innovation, and over investment. Macroeconomic modeling is dominated by a linear stationary model of the representative agent, which cannot explain the persistent nature of business cycles. The critical issues of non-integrable systems and continuous time are ignored by the regression approach in econometrics.

Based on nonlinear dynamic models of business cycles and division of labor, we are developing a biological framework of evolutionary economic dynamics. Starting from empirical analysis of the macroeconomic time series, we have abundant evidence about the endogenous nature of macroeconomic fluctuations. Based on our theoretical study, the birth–death process is a better alternative than the Brownian motion in the first approximation of stochastic growth (Ji 2003). Persistent cycles around the HP trend can be further refined by the deterministic model of color chaos in the soft-bouncing oscillator. Product cycles and excess capacity resulted from market-share competition.

From the biological perspective, business cycles are living rhythms with structural stability and dynamic resilience. Product cycles and business cycles are in the same range of time scale, ranging from several months or several years to decades. Examples are short cycles in computer software and long cycles in railway construction. Disruptive technology changes are the driving force of persistent business cycles. This perspective will fundamentally change our views on economic systems and government policies. Compared to the Fourier (plane wave) transform and pulse (noise) representation, the Gabor wavelet representation (or coherent state in quantum mechanics) provides a better mathematical representation for evolutionary ecology and economic dynamics. We will discuss the development of economic physics elsewhere.

We summarize the difference between the equilibrium-mechanical approach and the evolution-biological approach in Table 3.3.

From the above discussion, we can see that these two approaches are complementary to each other to some degree. However, the mechanical approach can be considered a special situation within a more general framework of a biological approach, since a conservative system is a special case of the open system.

In macro issues, the evolutionary approach can be a synthesis of conflicting linear theories. For example, the new classical school and the Keynesian school can be integrated into a general macro dynamics including different time scales: the new classical school mainly on the long run, Keynesians on medium term, and financial economists on short run. In our decomposition of macro indexes, the long run is the nonlinear (HP) smooth trend, the medium run is persistent cycles around the trend, and the short run is residual noise imposed on persistent cycles.

In micro issues, the evolutionary approach may establish a link between cost analysis on the demand side and market-share analysis on the supply side. Empirical observations of product cycles and marketing strategies in business research may provide a solid foundation for micro dynamics.

From our understanding, “dissipative structure” and “self-organization” means a higher kind of order in living systems, such as living rhythms, metabolism, and complex systems. The classical concept of equilibrium and entropy only describe the order-less state without differentiated structure. If we compare self-organization in complexity science with the equilibrium order shaped by “friction” or “rigidity” in equilibrium economics (Coase 1990), you may appreciate our new concepts of *market resilience* and *persistent cycles*. The central concept in cybernetics and economic science is “stability” under “negative feedback” (Wiener 1948). We propose the terms of *complexity* and *resilience* to combine the two aspects within living systems and social systems: *stability*

Table 3.3 Concepts and representations in mechanical and biological approach

Subject	*Mechanical*	*Biological*
Micro	Factor cost, marg. pricing	Prod. cycle, market-share compet.
Macro	Stability and convergence	Uneven growth and persist. cycles
Math	Static optimization	Nonlinear dynamics
Microfound.	One-body (representative)	Many-body problem
Test	Regression, forecast.	Natural and lab experiments
History	Ergotic (no memory)	Path-dependence
Information	Perfect/imperfect info.	Complexity, ambiguity
Decision	Individual rationality	Social learning
Risk	Risk-aversion	Risk-taking/risk-aversion
Strategy	Maximizing profit	Balancing opportunity/risk
Variable	Relative price	Market share
Order	Balance demand–supply	Technology competition
Technology	Fixed parameter	S-curve
Innovation	Random shocks	Disruptive stages
Pricing	Price taker (perfect mkt.)	Strategic pricing
	Price setter (monopols.)	Profit margin and growth space
Division of labor	Different commodities	Co-existence of technologies
Business cycles	External shocks	Endogenous cycles
Growth	Brownian motion	Birth–death and wavelets
Trend ref.	FD, LL, HP	HP
Fluctuations	Linear cycles + white noise	Nonlinear color chaos + white/fractal noise
Prediction	*Mechanical*	*Biological*
Price	Convergence	Differentiation
Development	Convergence (Solow)	Rise and fall of organizations
	Learning by doing	Learning by trying
Macro fluct.	Labor choice (Lucas)	Industrial competition
	Technology shocks (RBC)	Birth and death of technologies
	Money shocks (Friedman)	Excess capacity and over investment
	Labor rigidity (Keynes)	Structural and financial changes
Institution	Transaction costs	Trade-off between stability and complexity
	Coordination costs	
Socio-evolution	Convergence	Bifurcations in evolution tree
Policies	Laissez-faire (classical)	Regulations and standard
Governments	Demand-side policies	Supply-side policies
Institution	Property rights (Coase)	Strategies innovations

under small external shocks and *viability* under large environmental changes. Both features can be observed from parametric space in complex dynamics and stable regimes of time rhythms in WGQ representation.

The proposed trade-off theory between stability and complexity and the generalized Smith theorem may address a wide range of phenomena in living and social systems. We believe that economic science is facing a great transition from equilibrium thinking to an evolutionary paradigm. The efficacy of our approach to economic dynamics is open to future research and experiments.

Finally, I would like to quote James Buchanan (1991) regarding his prediction on the future of economics:

> The shift toward emergent order as a central perspective will be paralleled by a corollary, even if not necessary, reduction of emphasis on equilibrium models. The properties of systems in dynamic disequilibrium will come to centre stage, and especially as economics incorporates influences of the post-Prigogine developments in the theory of self-organizing systems of spontaneous order, developments that can be integrated much more easily into the catallactic than into the maximizing perspective.

Acknowledgments

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Part II

Macro vitality

Trend–cycle separation, economic chaos, and persistent cycles

4 Empirical and theoretical evidence of economic chaos[1]

4.1 Introduction

In recent years, there has been rapid progress in the studies of deterministic chaos, random behavior generated by deterministic systems with low dimensionality. This progress has been made not only in theoretical modeling, but also in experimental testing (Abraham *et al.* 1984). Chaotic models have been applied to a variety of dynamic phenomena in the areas of fluid dynamics, optics, chemistry, climate, and neurobiology. Applications to economic theory have also been developed, especially in business-cycle theory (see review article: Grandmont and Malgrange 1986).

Over the last century, the nature of business cycles has been one of the most important issues in economic theory (Zarnowitz 1985). Business cycles have several puzzling features. They have elements of a continuing wave-like movement; they are partially erratic and at the same time serially correlated. More than one periodicity has been identified in business cycles in addition to long growth trends. Most simplified models in macroeconomics address one of these features (Rau 1974), while system dynamics models describe economic movements in terms of a large number of variables (Forrester 1977).

Two basic questions arise in studies of business cycles. Are endogenous mechanism or exogenous stochastics the main cause of economic fluctuations?[2] And can complex phenomena be characterized by mathematical models as simple as, say, those for planetary motion and electricity?

The early deterministic approach to business cycles with well-defined periodicity mainly discussed the endogenous mechanism of economic movements. A linear deterministic model was first proposed by Samuelson (1939), which generated damped or explosive cycles. Nonlinearities were introduced in terms of limit cycles to explain the self-sustained wave-like movement in economics (Goodwin 1951).

A stochastic approach seems to be convenient for describing the fluctuating behavior in economic systems (Osborne 1959; Lucas 1981). The problem with the stochastic models, however, lies in the fact that random noise with finite delay terms (usually less than ten lags, in practice) only explains the short-term fluctuating behavior. Most aggregate economic data are serially correlated not only in the short term but also over long periods. Two methods dealing with long correlations are often used: longer lags in regression studies and multiple differencing time series in ARIMA models. Longer lags require estimating more "free parameters," while ARIMA models are essentially whitening processes that wipe out useful information about deterministic mechanism.

Actually, fluctuations may be caused by both intrinsic mechanism and external shocks. An alternative to the stochastic approach with a large number of variables and parameters, is deterministic chaos, with few variables or low-dimensional strange attractors (Schuster 1984). An attractor is a strange one if its dimensionality is a fractal rather than an integer number. For example, a fixed point solution is a zero-dimensional (normal) attractor; a limit cycle is a one-dimensional attractor, but the logistic chaos in discrete time (LCD) with a fractal dimension, is less than one. This is the approach adopted in the present chapter. Newly developed numerical techniques of nonlinear dynamics also shed light on a reasonable choice of the number of variables needed in characterizing a complex system.

An increasing number of works examine economic chaos. Most theoretical models are based on discrete time (Benhabib 1980; Stutzer 1980; Day 1982; Grandmont 1985; Deneckere and Pelikan 1986; Samuelson 1986, 1990), only one long wave model is based on continuous time (Rasmussen *et al.* 1985). Ongoing empirical studies are conducted by a few economists (Sayers 1985; Brock 1986; Scheinkman and LeBaron 1987; Ramsey and Yuan 1987; Frank and Stengos 1988). Some clues of nonlinearities have been reported, but no solid evidence of chaos has yet been found by these authors. Two efforts were made to fit nonlinear discrete models with empirical data (Dana and Malgrange 1984; Candela and Gardini 1986), but the parameters were found outside the chaotic regions.

We started the search for empirical evidence of chaos in economic time series in 1984. The main features of deterministic chaos, such as complex patterns of phase portraits and positive Lyapunov exponents, have been found in many economic aggregate data such as GNP and IPP, but most of our studies have failed to identify the dimensionality of attractors because of limited data. Then we tested monetary aggregates at the suggestion of W.A. Barnett. Low-dimensional strange attractors from weekly data were found in 1985, and a theoretical model of low-dimensional monetary attractors was developed in 1987 (Chen 1987b). A brief description of comprehensive studies of economic chaos is presented here for general readers.

In this chapter, a short comparison between stochastic and deterministic models is introduced. Positive evidence of low-dimensional strange attractors found in monetary aggregates is shown by a variety of techniques. A continuous-time model is suggested to describe the delayed feedback system in monetary growth. The period-doubling route to chaos occurs in the model (Feigenbaum 1978). The model offers an explanation for the low dimensionality of chaotic monetary time series and for the nature of business cycles and long waves. Finally, the implications of deterministic chaos in economics and econometrics are discussed.

4.2 Simple pictures of deterministic and stochastic processes

To what extent economic fluctuations around trends should be attributed to endogenous mechanism (described by deterministic chaos) or exogenous shocks (described by stochastic noise) is a question that can be addressed by empirical tests.

There are at least four possible candidates in describing fluctuating time series: linear stochastic process, discrete deterministic chaos, continuous deterministic chaos, and nonlinear deterministic chaos plus noise. The test of the last one is only in its infancy, because a high level of noise will easily destroy the subtle signal of deterministic chaos. We mainly discuss the first three candidates here and give numerical examples of white noise and deterministic chaos as the background for further discussions. The linear autoregressive AR(2) model adopted in explaining the fluctuations of log-linear detrended GNP time series (Brock 1986) is demonstrated as an example of a linear stochastic process. For deterministic chaos, two models are chosen: the discrete logistic model (May 1976), which is widely used in population studies and economics, and the continuous spiral chaos model (Rössler 1976).

The time sequences of these models are shown in Figure 4.1. They seem to be equally capable to describe economic fluctuations when appropriate scales are used to match real time series. But closer examination reveals the differences among them.

4.2.1 Phase space and phase portrait

From a given time series X(t), an m-dimensional vector V(m, T) in phase space can be constructed by the m-history with time delay T: V(m, T) = {X(t), X(t + T),…, X[t + (m – 1)T]}, where m is the embedding dimension of phase space (Takens 1981). This is a powerful tool in developing numerical algorithms of nonlinear dynamics, since it is much easier to observe only one variable to analyze a complex system.

The phase portrait in two-dimensional phase space X(t + T) versus X(t) gives clear picture of the underlying dynamics of a time series. With the fixed point solution (the so-called zero-dimensional attractor), the dynamical system is represented by only one point in the phase portrait. For periodic solution (the one-dimensional attractor), its portrait is a closed loop. Figure 4.2 displays the phase portrait of the three models. The nearly uniform cloud of points in Figure 4.2a closely resembles the phase portrait of random noise (with infinite degree of freedom). The curved image in Figure 4.2b is characteristic of the one-dimensional unimodal chaos in discrete time. The spiral pattern in Figure 4.2c is typical of a strange attractor whose dimensionality is not an integer. Its wandering orbit differs from periodic cycles.

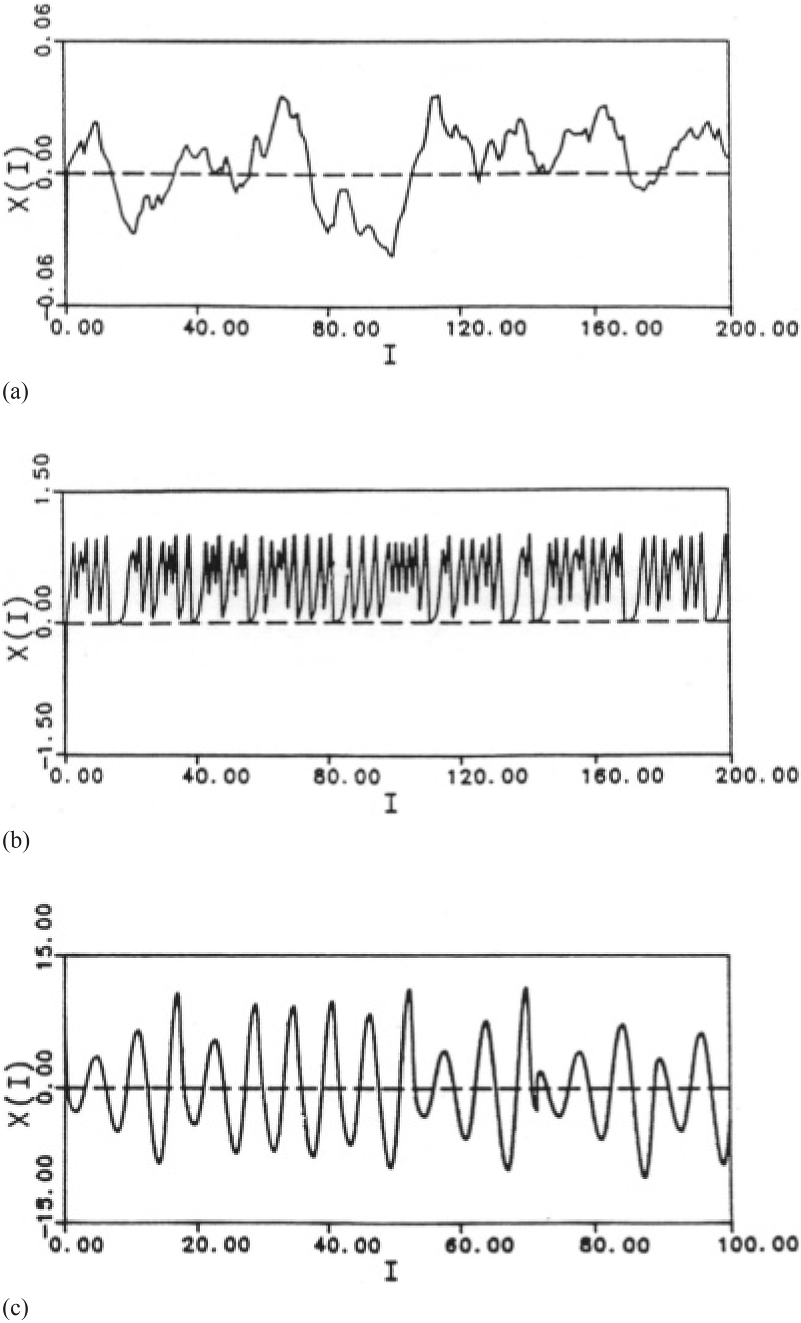
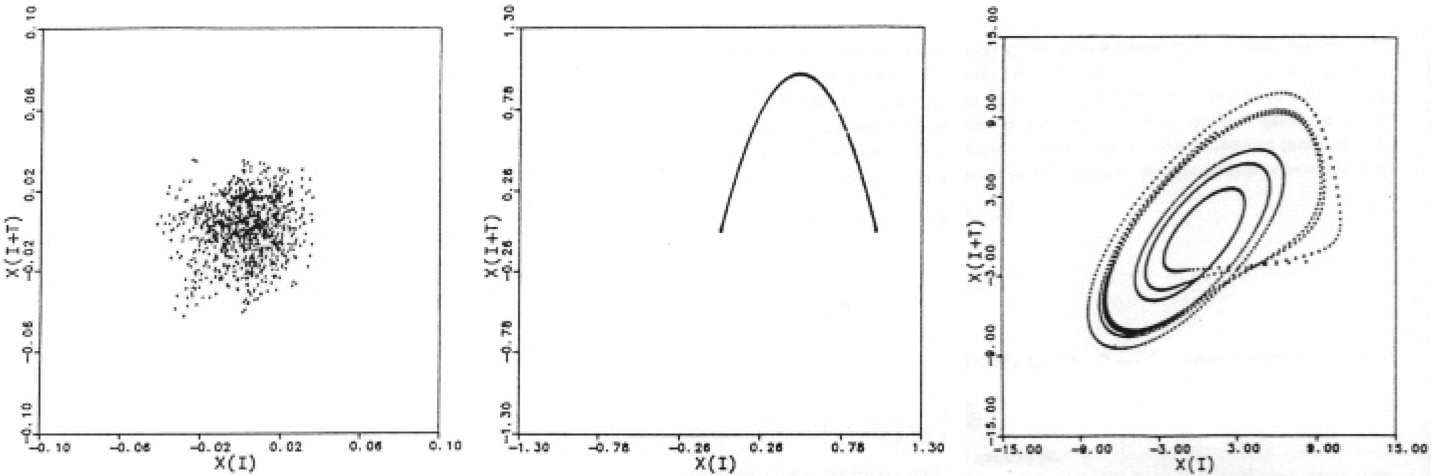


Figure 4.1 The seemingly erratic time series of linear and nonlinear models. (a) AR(2). (b) Logistic chaos in discrete time. (c) Rössler chaos in continuous time.



(a) (b) (c)

Figure 4.2 The phase portraits X(I) vs. X(I + T) of three models in Figure 4.1. (a) The random image of AR(2). (b) The arch-type pattern of LCD. (c) The spiral pattern of RCC.

Note
Three dynamic models show three distinctive patterns in their phase portraits.

4.2.2 Long-term autocorrelation

The autocorrelation function is another useful concept in analyzing time series. The autocorrelation function AC(I) is defined by

$$AC(I) = AC(t' - t) = \frac{COV[X(t'), X(t)]}{E[X(t) - M)^2]}$$

where M is the mean of X(t) and cov[X(t′), X(t)] is the covariance between X(t′) and X(t). They are given by

$$M = E[X(t)] = \frac{\sum_{t=1}^{N} X(t)}{N}$$

$$COV(X(t'), X(t)) = E[(X(t') - M)(X(t) - M)]$$

It is known that the autocorrelation function of the periodic motion is periodic and that of the white noise is a delta function. Figure 4.3 shows autocorrelations of the AR(2) process quickly decay to small disturbances. The autocorrelations of the logistic chaos in discrete time (LCD) look the same as those of white noise. The Rössler attractor in continuous time (RCC) displays some resem-

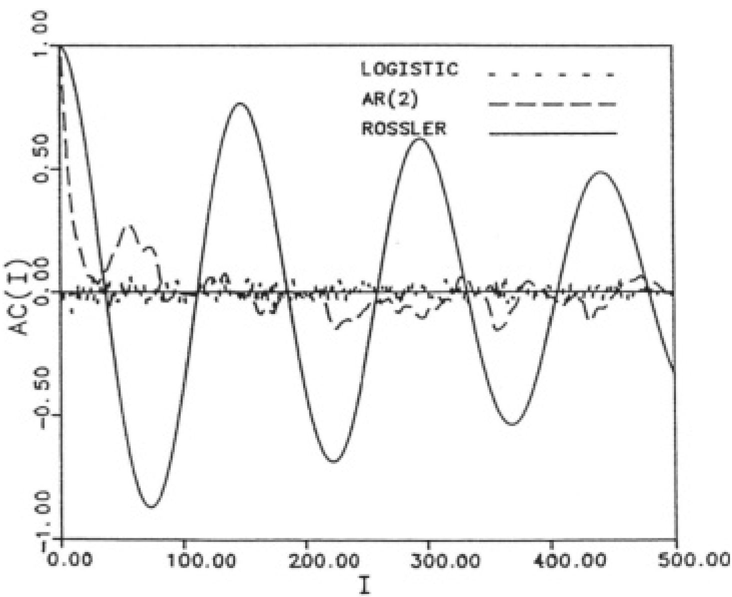


Figure 4.3 The autocorrelations of the three models in Figure 4.1.

Notes
Autocorrelation of AR(2) looks like dampened noise; LCD likes white noise; RCC seems damped harmonic cycles.

blance to periodic cycles. Its autocorrelations have initial exponential decay after a characteristic decorrelation time $T_{d,}$ followed by wave-like fat tails. T_d is determined by the time lag of the first vanishing autocorrelations.

4.3 Testing economic chaos in monetary aggregates

Testing economic aggregate time series is a complex process, since they contain growth trends. Not all the techniques in nonlinear dynamics developed by mathematicians and physicists (Mayer-Kress 1986) are applicable to economic time series. For example, Poincáre sections used in physics require more than several thousand data points. Data quantity and data quality are crucial in applying the currently existing techniques.

After introducing the monetary indexes, we focus on the testing and modeling of monetary aggregates. The data source is Fayyad (1986).

4.3.1 Monetary aggregates

Observable indicators are essential to empirical investigations. In simple physical systems, some macroscopic quantities (such as mass and energy) can be simple summation of microscopic quantities. The right choice of aggregate indexes for economic system remains an issue on which there is no consensus. For example, there are 27 component monetary assets – currency, traveler checks, demand deposit, eurodollars, money market deposit, saving deposit, Treasury securities, commercial paper, and so on – according to the Federal Reserve's latest classification of the American monetary system. Four levels of simple-sum aggregate indexes, M1, M2, M3, and L, consisting of six to 27 monetary assets, are used by the Federal Reserve. There are also parallel theoretical indexes, such as Divisia monetary aggregates, initiated by W.A. Barnett. Better aggregate indexes are needed to describe macroeconomic movements by simple mathematical methods.

We tested 12 types of monetary index time series including official simple-sum monetary aggregates (denoted by SSM), Divisia monetary demand aggregates (DDM), and Divisia monetary supply aggregates (DSM); each yielded about 800 weekly data points between 1969 and 1984. Five of them were successful in testing strangeness: simple-sum SSM2, Divisia demand DDM2, DDM3, DDL, and Divisia supply DSM2 monetary aggregates. The behaviors of Divisia aggregates are very similar. We only discuss SSM2 and DDM2 here for brevity. The exponential growth trends of these time series are shown in Figure 4.4.

4.3.2 Observation reference and first difference detrending

Mathematical models with attractor solutions can greatly simplify descriptions of complex movements without obvious growth trends. The choice of detrending methods basically is a choice of reference system or transformation theory. Detrending is a solved problem for physicists when observations of physical

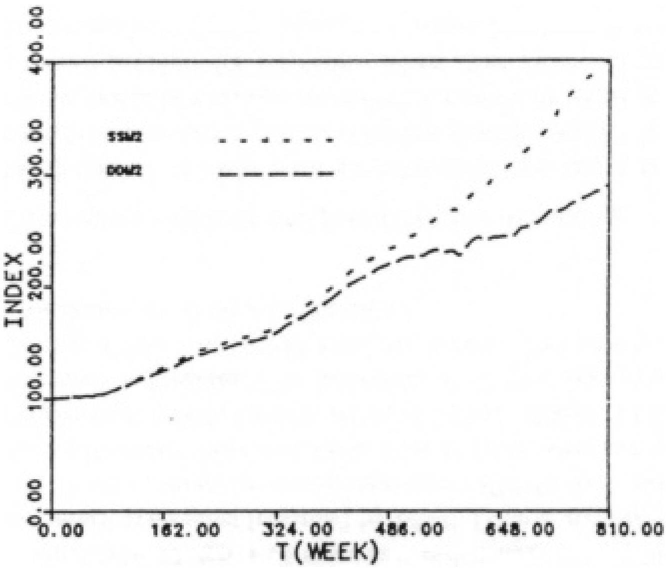


Figure 4.4 The seemingly exponential growth trends of weekly monetary aggregates SSM2 and DDM2 (January 1969–July 1984).

systems are conducted in appropriate inertial reference systems. However, it is an unsolved issue in testing economic time series. How to choose a reference system to observe the global features of economic movements is a critical question for identifying the deterministic mechanisms of economic activities. We attempt to answer this question through numerical experiments on empirical data.

The percentage rate of change and its equivalent form, the logarithmic first differences, are widely used in fitting stochastic econometric models (Osborne 1959; Friedman 1969a). It can be defined as follows:

$$Z(t) = \ln S(t+1) - \ln S(t) = \ln\left[\frac{S(t+1)}{S(t)}\right]$$

where S(t) is the original time series, and Z(t) is the logarithmatic first difference. Its ineffectiveness for observing chaos will be shown later.

4.3.3 Log-linear detrending and growth cycles

We detrended data using log-linear detrending which was suggested by W.A. Barnett. The same detrending was also been used by other economists (Dana and Malgrange 1984; Brock 1986). In log-linear detrending, we have

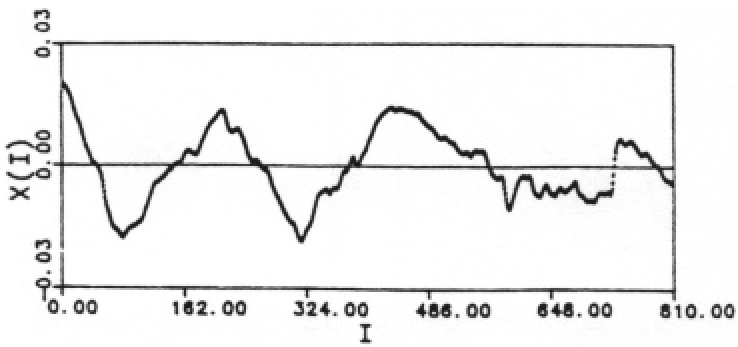
$$X(t) = \ln S(t) - (k_0 + k_1 t)$$

Or

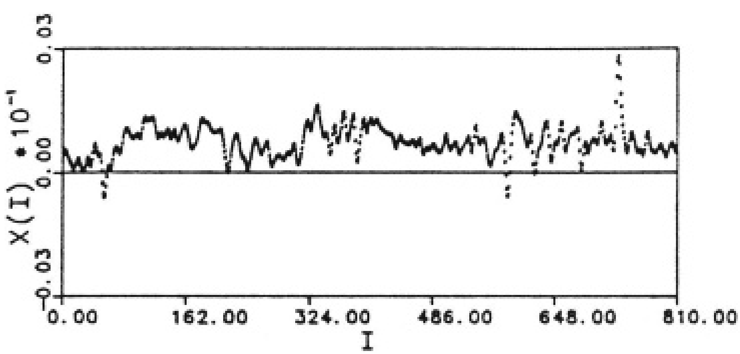
$$S(t) = S_0 \, e^{k_1 t} \, e^{X(t)}$$

where S(t) is the original time series, and X(t) is the resulting log-linear detrended time series, k_0 is the intersection, k_1 the constant growth rate, and $S_0 = \exp(k_0)$.

After numerical experiments on a variety of detrending methods and economic time series, we finally found that the percentage rate of change and its equivalent methods are whitening processes based on short-time scaling. Log-linear detrending, on the other hand, retains the long-term correlations in economic fluctuations, since its time scale represents the whole period of the available time series. Findings of evidence of deterministic chaos mainly from log-linear detrended economic aggregates lead to this conclusion. Figure 4.5a shows the time sequences of the log-linear detrended (denoted by LL) monetary aggregates SSM2. Its almost symmetric pattern of nearly equal length of expansion and contraction is a typical feature of growth cycles in economic systems. The usual business cycles are not symmetrical, their longer expansions and



(a)



(b)

Figure 4.5 Two typed of detrending for time series SSM2. (a) Symmetric LL (log-linear). (b) Asymmetric FD (first differencing of log series).

shorter contractions can be obtained by superimposing a trend with constant growth rate adding to the symmetric growth cycles. The logarithmic first difference time series (denoted by FD) SSM2 is given in Figure 4.5b as a comparison. The latter is asymmetric and more erratic.

4.3.4 Empirical evidence of deterministic and stochastic processes

Based on the phase portrait and autocorrelation analysis, we can easily distinguish qualitatively a stochastic process from a deterministic one. A comparison between IBM daily stock returns and monetary aggregates follows.

Figure 4.6a presents the phase portrait of detrended monetary aggregates SSM2 LL. It rotates clockwise like the spiral chaos in Figure 4.2c. The complex

(a)
(b)

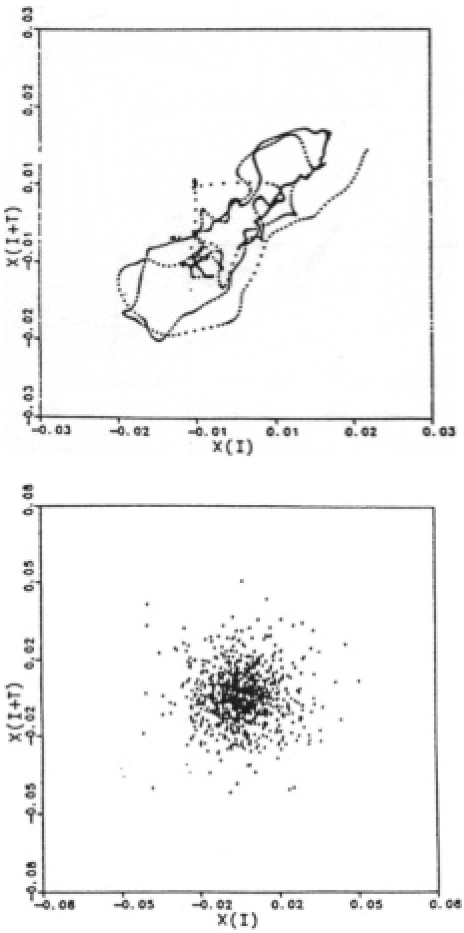


Figure 4.6 The phase portraits of two types of detrended time series. (a) SSM2 LL. (b) IBM daily returns.

pattern is a potential indication of nonlinear deterministic movements and eliminates the possibilities of white noise or simple periodic motions. The phase portrait of IBM daily stock returns is shown in Figure 4.6b. It closely resembles Gaussian white noise. It is consistent with previous findings in economics (Osborne 1959; Fama 1970). The autocorrelations of the detrended time series are shown in Figure 4.7. Readers may compare these with the autocorrelations in Figure 4.3.

If we approximate the fundamental period T_1 by four times the decorrelation time T_d, as in the case of periodic motion, then, T_1 is about 4.7 years for SSM2 LL, which is very close to the common experience of business cycles. We will return to this point later.

4.3.5 The numerical maximum Lyapunov exponent

Chaotic motion is sensitive to initial conditions. Its measure is the Lyapunov exponents, which are the average exponential rates of divergence or convergence of nearby orbits in phase space. Consider a very small ball with radius $\varepsilon(0)$ at time $t = 0$ in the phase space. The ball may distort into an ellipsoid as the dynamical system evolves. Let the length of the i-th principal axis of this ellipsoid at time t be $\varepsilon_i(t)$. The spectrum of Lyapunov exponents λ_i from an initial point can be obtained theoretically by (Farmer 1982):

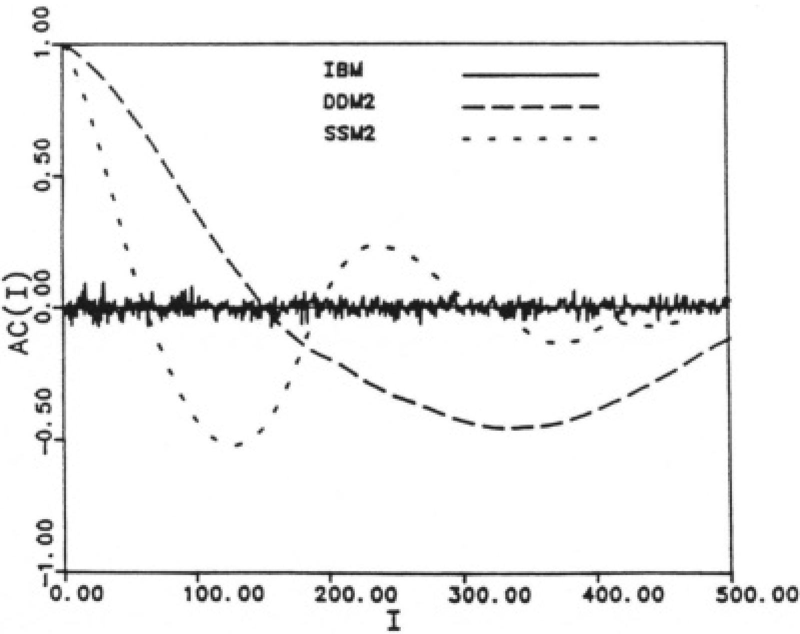


Figure 4.7 Autocorrelation functions of three empirical time series (SSM2 LL, DDM2 LL, IBM daily stock returns).

$$\lambda_j = \lim_{t\to\infty}\lim_{\varepsilon(0)\to 0}\left\{\frac{\ln[\varepsilon_j(t)/\varepsilon_j(0)]}{t}\right\}$$

The maximum Lyapunov exponent λ (the largest among λ_j) can be calculated numerically by the Wolf algorithm (Wolf *et al.* 1985) where the limiting procedure is approximated by an averaging process over the evolution time EVOLV. This algorithm is applicable when the noise level is small. A sketch of the algorithm is shown in Figure 4.8. The maximum Lyapunov exponent λ is negative for stable systems with fixed points, zero for periodic or quasiperiodic motion, and positive for chaos.

In theory, the maximum Lyapunov exponent is independent of the choice of evolution time EVOLV, embedding dimension m and time delay T. In practice, the value of Lyapunov exponent does relate to the numerical parameters. The range of evolution time EVOLV must be chosen by numerical experiments. The positive maximum Lyapunov exponents of the investigated monetary aggregates are stable over some region in evolution time shown in Figure 4.9. The numerical Lyapunov exponent is less sensitive to the choice of embedding dimension m. In our tests, we fixed m at five and time delay T at five weeks based on the numerical experiments. For example, the stable region of EVOLV is 45–105 weeks for SSM2 and 45–150 weeks for DDM2. Their average maximum Lyapunov exponent λ over this region are 0.0135 and 0.0184 (bit per week), respectively.

The characteristic decorrelation time T_d of the SSM2 LL is 61 weeks. The reciprocal of the maximum Lyapunov exponent λ^{-1} (= 74.1) for SSM2 LL is roughly of the same order of magnitude as the decorrelation time T_d (Nicolis and Nicolis 1986). This relation does not hold for pure white noise.

4.3.6 The correlation dimension

The most important characteristic of chaos is its fractal dimension (Mandelbrot 1977), which provides a lower bound to the degrees of freedom for the system (Grassberger and Procaccia 1983, 1984). The popular Grassberger–Procaccia algorithm estimates the fractal dimension by means of the correlation dimension D. The correlation integral $C_m(R)$ is the number of pairs of points in

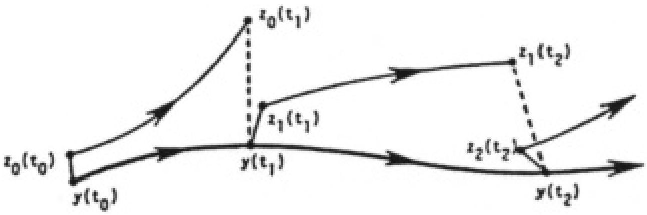


Figure 4.8 An artist's sketch of the Wolf algorithm for calculating Lyapunov exponents.

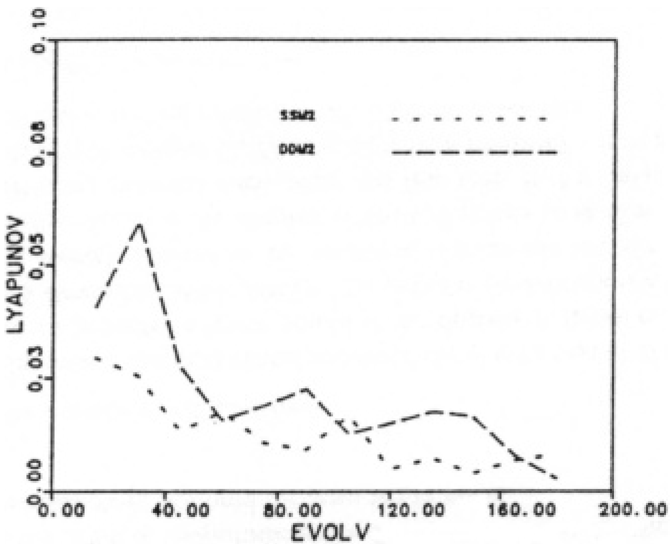


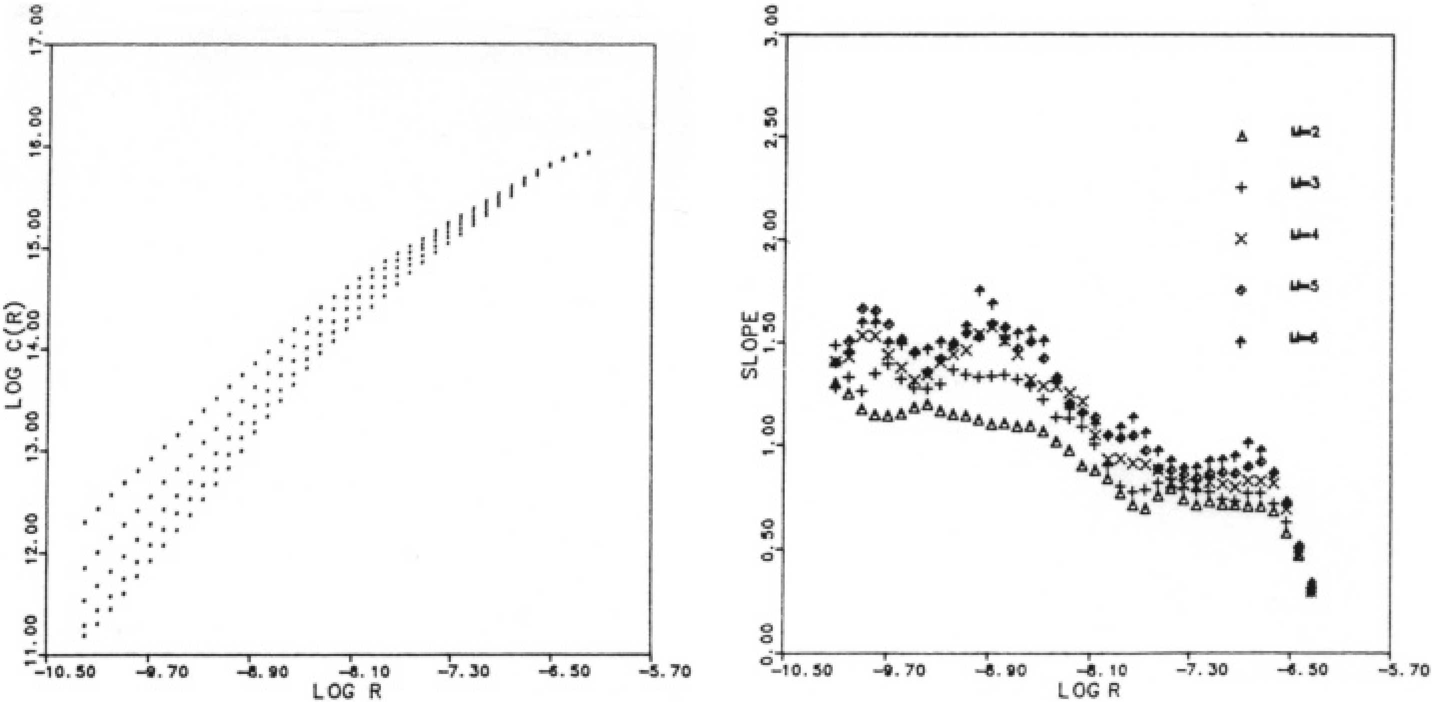
Figure 4.9 The maximum Lyapunov exponents of SSM2 and DDM2 LL series.

m-dimensional phase space whose distances between each other are less than R. For random or chaotic motion, the correlation integral $C_m(R)$ may distribute uniformly in some region of the phase space and has a scaling relation of R^D. Therefore, we have

$$\ln_2 C_m(R) = D \ln_2 R + C$$

Here, D and C are constant. For white noise, D is an integer equal to the embedding dimension m. For deterministic chaos, D is less than or equal to the fractal dimension. The Grassberger–Procaccia plots of $\ln C_m(R)$ versus lnR and slope versus log R for SSM2 LL and DDM2 LL are shown in Figures 4.10 and 4.11. When R is too large, $C_m(R)$ becomes too saturate at the total number of data points (see the right-hand regions of Figures 4.10 and 4.11). When R is too small, the algorithm detects the noise level of the data (see the left-hand regions of Figures 4.10 and 4.11). The existence of linear regions of intermediate R, which reflect the fractal structure of the attractors, is shown in Figures 4.10a and 4.11a. The correlation dimension can be determined from the saturated slope of the plateau region in Figures 4.10b and 4.11b.

We found that the correlation dimensions of the investigated five monetary aggregates, including four Divisia monetary indexes and one official simple-sum monetary index, were between 1.3 and 1.5. For other monetary aggregates, no correlation dimension could be determined. These findings are consistent with previous studies in economic aggregation theory and index number theory, which indicate that, except for SSM2, Divisia monetary aggregates are better indexes than simple-sum monetary aggregates (Barnett *et al.* 1986; Barnett and Chen 1988).

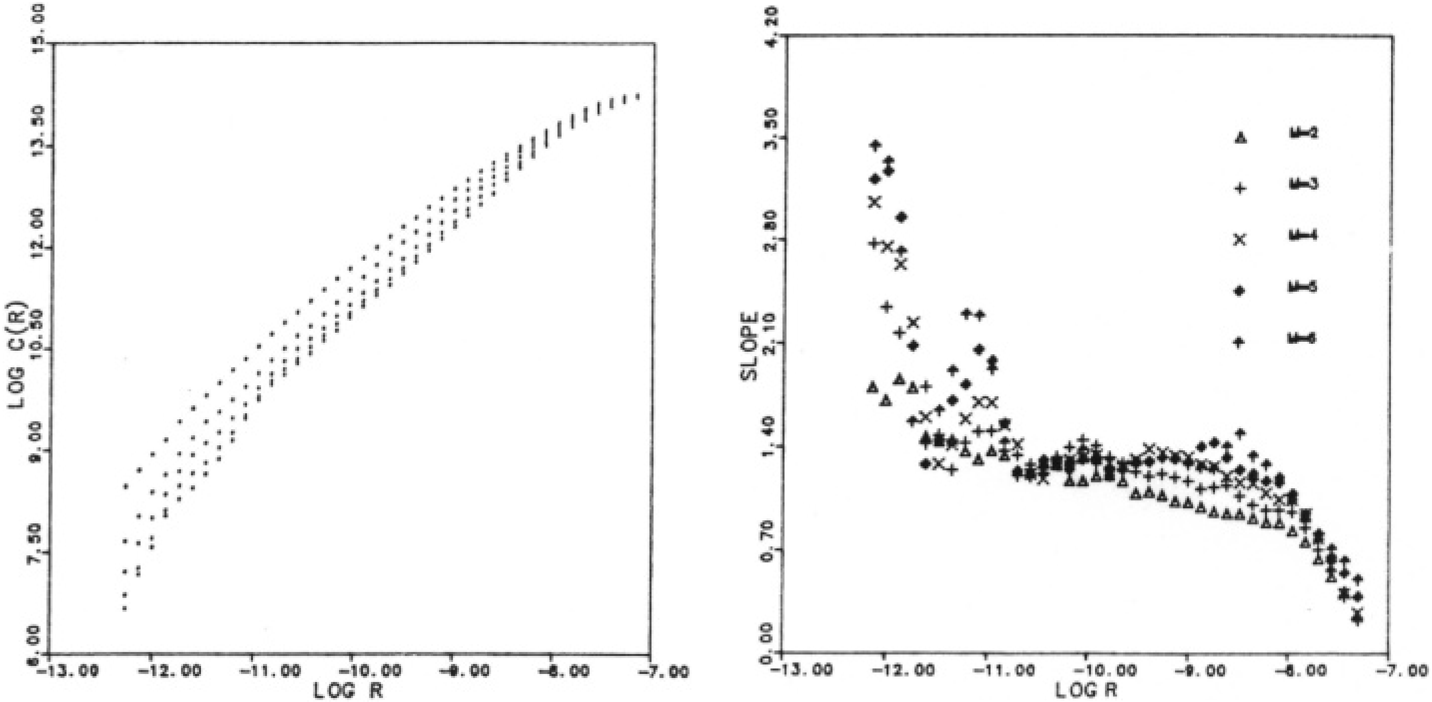


(a)

(b)

Figure 4.10 The Grassberger–Procaccia plots for calculating correlation dimension of SSM2 LD series. (a) Log C(R) vs. Log R. (b) Slope vs. Log R.

Note
The correlation dimension D = 1.5.



(a) (b)

Figure 4.11 The Grassberger–Procaccia plots for calculating correlation dimension of DDM2 LL series.

Note
The correlation dimension D = 13.

4.3.7 Some remarks about numerical algorithms

Given a deterministic attractor whose correlation dimension is D, we first ask how many data points are needed to determine the dimensionality D (Greenside *et al.* 1982). The minimum data points N_D with a D-dimensional attractor can be estimated by scaling relation h^D, where the constant h varies with attractors. Practically, we can only identify low-dimensional attractors with finite data sets, since N_D increases exponentially with D. For the Mackey–Glass model (1977), 500 points are needed for D = 2 and more than 10,000 points for D = 3. In the Couette–Taylor experiment, N_D is about 800 points for D = 2.4, 40,000 points for D = 3, and 50 billion points for D = 7 (Brandstater and Swinney 1987). This issue seems to be ignored by some economists. For example, in Brock (1986), the correlation dimension of GNP with 143 quarterly data points was calculated under the extremely high embedding dimension (m = 20) without showing the linear region of the Grassberger–Procaccia plots. In our experience, the width of the linear region shrinks rapidly to zero when m increases beyond six, as seen in Figure 4.10 and 4.11. Practically, m is large enough when m reaches 2D + 1.

There is another concern about the time expansion covered by the time series. In physics experiments, the sampling rate is typically 10–100 points per orbit. Therefore, 100–1000 periods are needed for D = 3 and 5–50 periods for D = 2. We tested this estimation in terms of the Mackey-Glass attractor. When the time delay τ is 17, its correlation dimension D is 1.95 calculated with 25,000 points (Grassberger and Procaccia 1983). To compare this result, we estimated the correlation dimension under a variety of sampling rates and time periods. We find the error is within 1 percent with 100 periods, 3 percent with 30 periods, 8 percent with ten periods, and 18 percent with five periods when using 1000–3000 data points. Similar results are obtained for the model we develop later.

It should be noted that there is no unique approach to identify deterministic chaos with certainty. Several algorithms that may be complementary were used in our tests. At present, with only hundreds of data points, the discovery of economic strange attractors whose dimensionality is higher than three is unlikely.

We can only speculate why we were unable to identify correlation dimensions for other types of economic time series, such as GNP, IPP, and the Dow-Jones indexes, in our numerical tests. Either their dimensions are too high to be estimated for limited data, or their noise levels are too large to recover the subtle information of deterministic chaos.

4.4 A delayed feedback model of economic growth

Let us consider modeling the low-dimensional monetary strange attractors as growth cycles. There are several problems to be solved: time scale, dynamic mechanism, and system stability.

4.4.1 Continuous versus discrete time

Current economic studies are dominated by discrete models. Economists favor discrete models because economic data are reported discretely in years, quarters, or months, and because discrete models are easier for numerical regression. However, continuous-time models are needed when the serial correlation of disturbances can no longer be neglected (Koopmans 1950). The decorrelation time T_d of the autocorrelations of time series sets a lower bound to the time unit of the discrete model. For a typical discrete model, T_d is in approximately the same length as the discrete time unit. The decorrelation time T_d for LL detrended monetary attractors is more than 60 weeks. The time scales of discrete models of deterministic chaos with one or two variables in business-cycle theory is typically one or two time units (Benhabib 1980; Day 1982; Grandmont 1985). The time scale of realistic business cycles are much larger (Sims 1986; Sargent 1987). Clearly, the simple discrete model is not appropriate to describe monetary growth cycles. A continuous model is needed for the monetary time series.

The observed low correlation dimension of monetary aggregates sets additional constraints to the theoretical modeling of growth cycles. The minimum number of degrees of freedom required for chaotic behavior in autonomous differential equations is three (Ott 1981), so the fractal dimension will be larger than two. Therefore, the driven oscillator in the long-wave model (Rasmussen *et al.* 1985) is not applicable in our case, since the observed correlation dimension in monetary chaos is less than two.

After comparing the correlation dimension and the phase portraits of existing models, we believe that the delay-differential equation is a good candidate for modeling low-dimensional monetary growth cycles. For simplicity, we consider only one variable here, which is the simplest model of monetary chaos. The low dimensionality of monetary attractors leads to the belief of the separability of the monetary deviations from other macroeconomic movements that are integrated in the natural trends of monetary growth rate.

4.4.2 Deviations from the trend and feedback behavior

The apparent monetary strange attractors are mainly found in log-linear detrended data. This is an important finding to study control behavior in monetary policy. We believe that the human ability to manage information is limited even if decision makers have "perfect information." Economic behavior is more likely following some simple rule of thumb or than finding global optima (Simon 1979). We assume that the general trends of economic development, the natural growth rate, are perceived by people in economic activities as a common psychological reference or as the anchor in observing and reacting (Tversky and Kahneman 1974). Administrative activities are basically reactions to deviations from the trend. We choose the deviation from the natural growth rate as the main variable in the dynamic model of monetary growth.

There are a number of delay-differential models in theoretical biology and population dynamics (Mackey and Glass 1977; May 1980; Blythe *et al.* 1982; Chow and Green 1985). Our model has a new feature which differs from previous models of population dynamics: its wave pattern should be symmetric, because we are dealing with detrended growth cycles. The wave form of business cycles is not symmetric, since they are observed in terms of the first difference of logarithmatic macroeconomic indexes or annual percent rate of growth. In an economic system moving with a constant growth rate, we define the reference equilibrium state as zero. The proposed equation is:

$$\frac{dX(t)}{dt} = aX(t) + F[X(t-\tau)] \tag{4.1}$$

$$F(X) = XG(X) \tag{4.2}$$

X here is the relative growth index, which measures the deviation from the trend. τ is the time delay, a is the expansion speed, F is the control function, and G is the feedback function.

There are two competing mechanisms in the growth system. The first is the stimulative growth that is an instantaneous response to market demand. It is described by the first term on the right of equation (4.1). A linear term for exponential growth is used for mathematical simplicity. The second term represents the endogenous system control described by the control function F. This consists of feedback signal $X(t - \tau)$ and feedback function G. The time delay τ exists in the feedback loop because of information and regulation lags (Friedman 1961).

4.4.3 The flow diagram and the symmetric control function

Figure 4.12 shows a flow diagram to describe our model. There are several considerations in specifying F and G. We assume the control function F(X) has two extrema at $\pm X_m$ for the control target floor and ceiling (Solomon 1981). G(X) should be nonlinear and symmetric, $G(-X) = G(X)$, in order to describe the overshooting in economic management and the symmetry in growth cycles. These features are essential to generate complex behavior in the economic growth model.

In choosing the form of G, we do not use the polynomial function adopted in previous models with relaxation oscillations, since its wave form is far from the observed monetary growth cycles. Here, we suggest a simple exponential function to describe negative feedback reactions.

$$G(X) = -b\exp\left(-\frac{X^2}{\sigma^2}\right) \tag{4.3}$$

where b is the control parameter, σ is the scaling parameter, and the extrema of F(X) are located at $X_m = \pm\frac{\sigma}{\sqrt{2}}$. Substituting equation (4.3) and (4.2)

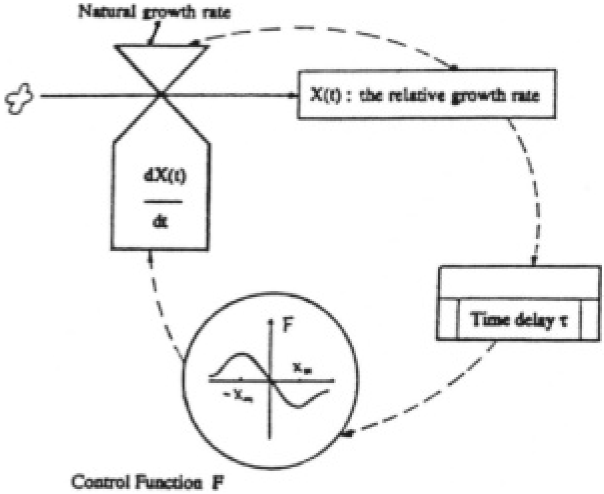


Figure 4.12 The flow diagram for a delayed feedback system with a target and soft-bouncing boundaries.

into equation (4.1) gives the following one-dimensional delay-differential equation:

$$\frac{dX(T)}{dt} = a\,X(t) - b\,X(t-\tau)\,\exp\left(-\frac{X(t\text{-}\tau)^2}{\sigma^2}\right) \tag{4.4}$$

We may change the scale by $X = X'\sigma$ and $t = t'$, then drop the prime for convenience:

$$\frac{dX(T)}{dt} = a\tau X(t) - b\tau X(t-1)\exp(-X(t-1)^2) \tag{4.5}$$

The rough behavior of the time delay equation (4.5) can be discussed in terms of linear stability analysis in determining the boundaries of damped and divergent oscillations in the parameter space.

We should point out that the exponential function in feedback function is a new feature of soft boundaries. In physics literature, hard boundary is used very often when a particle has elastic collision to a hard wall. In human behavior, we often observe soft boundaries, such as the case of driving on a high-speed freeway with lower and higher speed limits. People often observe the rule in a rough sense. Therefore, our model can be named as a soft-bouncing oscillator, which is generated by a feedback mechanism with soft boundaries, i.e., a control target with limit floor and ceiling.

4.4.4 The period-doubling route to chaos

We solved equation (4.5) numerically by the predictor-corrector approach. Time sequences and phase portraits of solutions with varying b for fixed a and τ are shown in Figures 4.13 and 4.14. In order to identify the route to chaos, the power spectra are shown in Figure 4.15. The period-doubling route to chaos is observed when parameter changes induce bifurcations (Feigenbaum 1978). One observes the fundamental frequency f_1 and its subharmonic frequency f_2 before and after transition to chaos in Figure 4.15c. In addition to period-1 orbit P1 (limit cycle) in Figure 4.14a, period-2 orbit P2 in Figure 4.14b and period-3 orbit P3 in Figure 4.14d, we also observe P4, P8, and P6 in the regions close to P2 and P3, respectively. The period-doubling route to chaos has also been found in other delay-differential models with asymmetric solutions (May 1980).

4.4.5 Phase transition and the pattern stability

A more useful approach is to study the waveform of business cycles, since spectral analysis is difficult to apply with the few cycles of data available in economic time series.

The observed periodic repetition often consists of basic patterns with several shorter cycles. We define the number of shorter cycles in a basic wave pattern as the cycle number Ck. The basic pattern may have L large amplitude oscillations followed by S small amplitude oscillations. Each periodic state can be labeled the cycle number, Ck = L + S. For example, the periodic states in Figures 14a, 14b, and 14d can be labeled C1, C2, and C3, respectively.

We should point out that the cycle number Ck is not necessarily equal to the period number P. For example, the wave form of P6 is C3, and those of P4 and P8 are belong to C2.

The phase diagram in terms of cycle number of the solutions is useful in characterizing economic long waves. Figures 4.16a and 4.16b display qualitatively the phase diagram of equation (4.5) in the parameter space. The broad diversity of dynamical behavior includes steady state ST, limit cycle or periodic motion C1, and explosive solution EP. The complex regime CP includes alternate periodic state (C1, C2, C3) and chaotic regime CH.

When parameter values change within each region, the dynamic behavior has the pattern stability, because the dynamic mode occupies a finite area in the parameter space. The phase transition occurs when parameters cross the boundary between different phases or patterns. It is observable when the wave pattern changes.

The notation of cycle number Ck is introduced for possible application in analyzing long waves. An interesting feature of the model is that only three periodic patterns C1, C2, and C3 have been found. The model gives an simple explanation of multi-periodicity in business cycles.

It is speculated that no unique periodicity is involved in the business cycles. In addition to seasonal changes, several types of business cycles have been

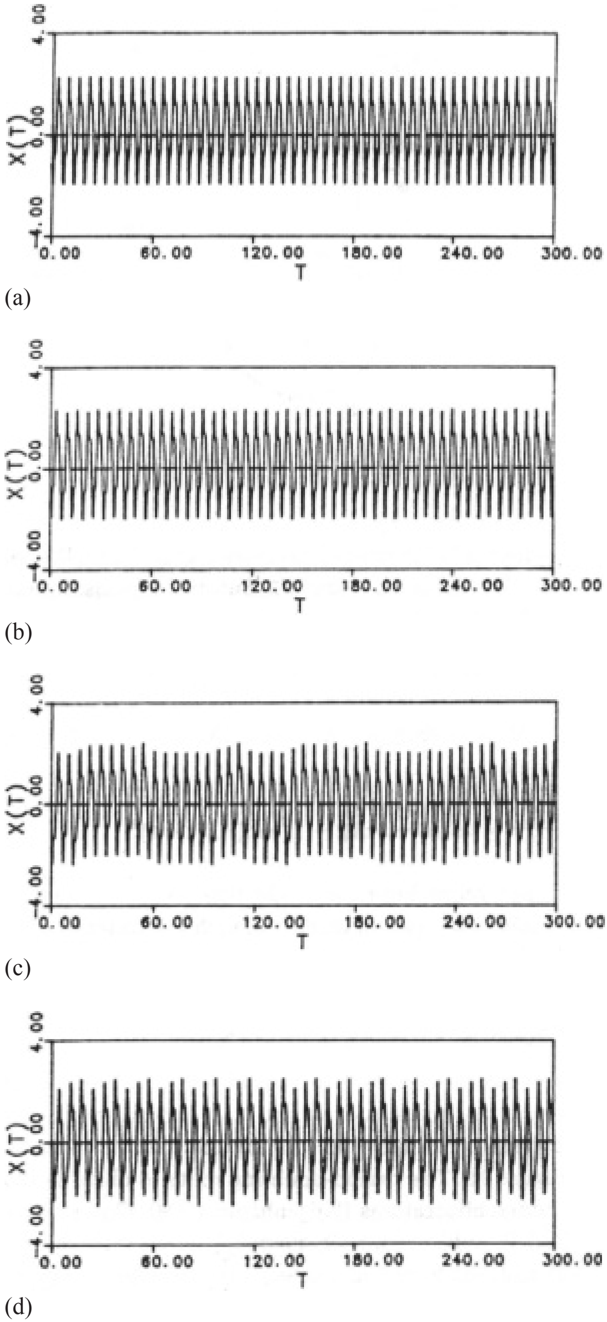
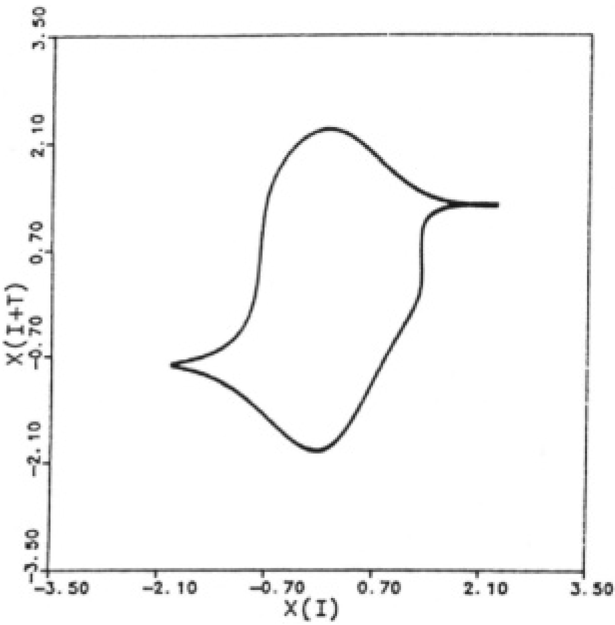
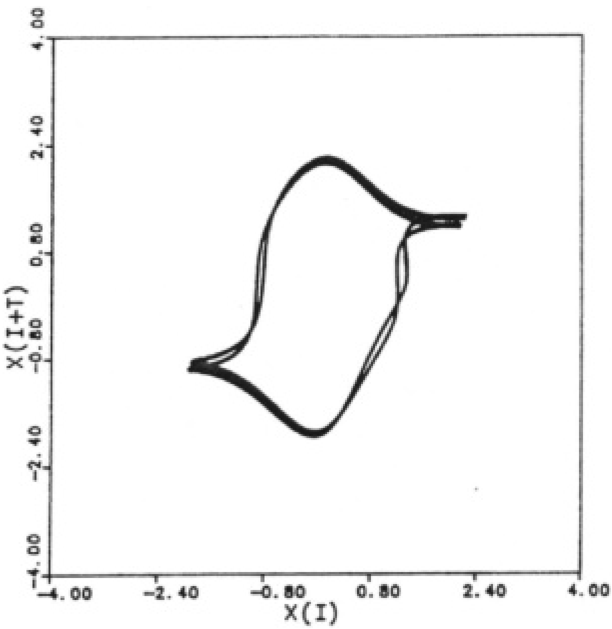


Figure 4.13 Time sequences of the numerical solutions of equation (4.13), the soft-bouncing oscillator (SBO). (a) C1. (b) C2. (c) CH. (d) C3.

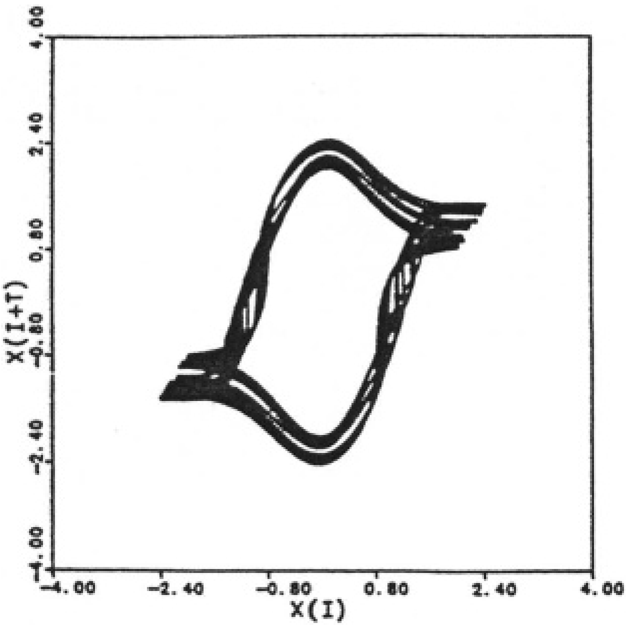


(a)

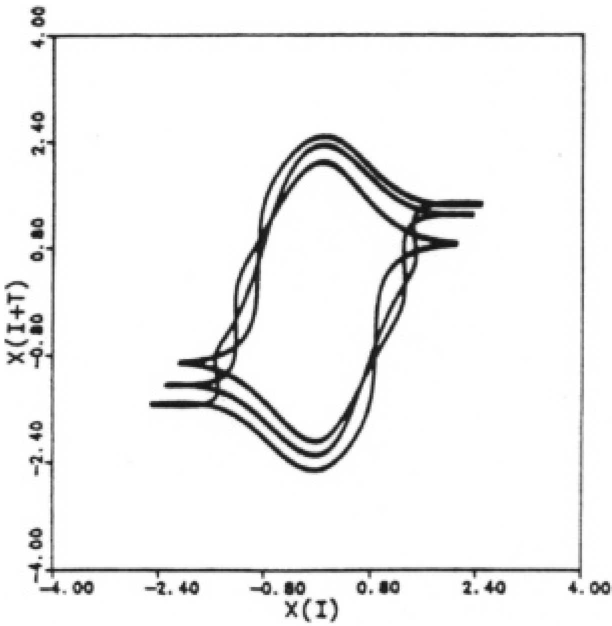


(b)

Figure 4.14 The phase portraits of SBO time series. (a) C1. (b) C2. (c) CH. (d) C3.

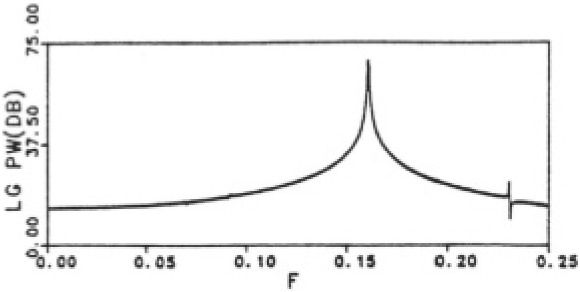


(c)

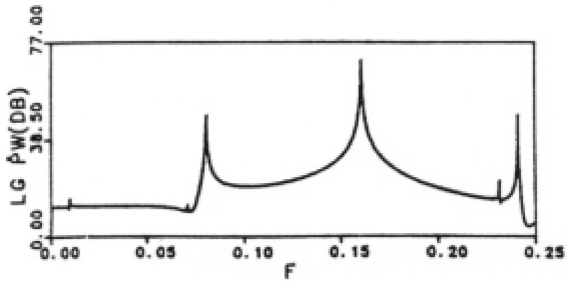


(d)

Figure 4.14 Continued.



(a)



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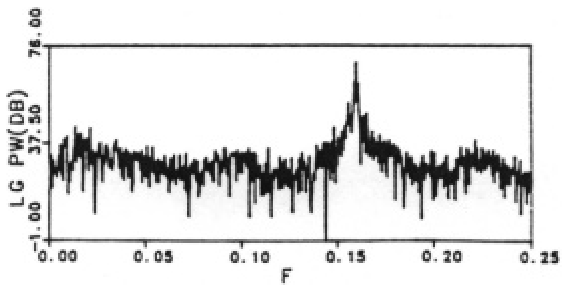

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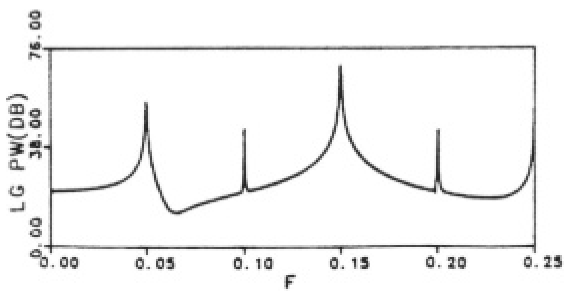
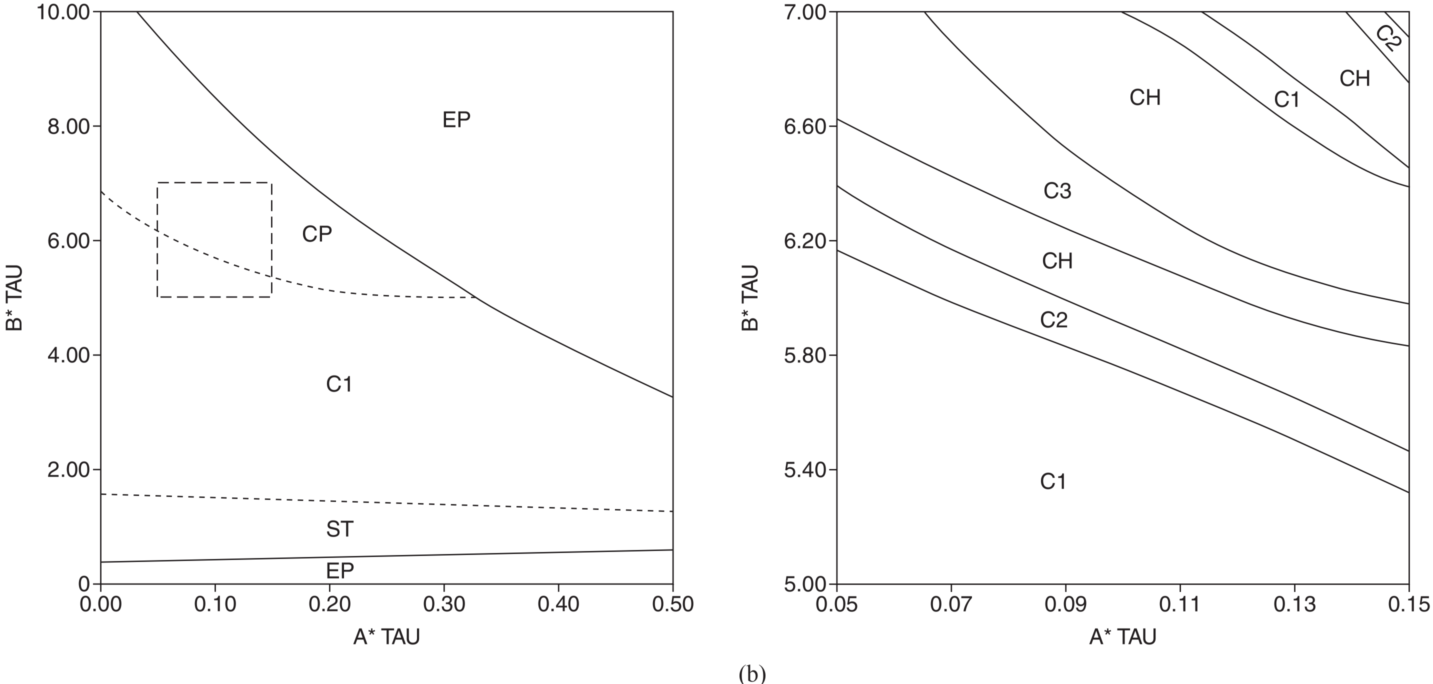


(d)

Figure 4.15 Power spectra of SBO time series.(a) C1. (b) C2. (c) CH. (d) C3.



(a)

(b)

Figure 4.16 Phase diagram of SBO numerical solutions in parameter space.

Note
Pattern stability and regime switch appear within or cross boundaries.

identified by economists (Van Duijn 1983). The Kitchin cycles usually last three to five years; the Juglar cycles, 7–11 years; the Kuznets cycles, 15–25 years; and Kondratieff cycles, 45–60 years. Schumpeter suggested that these cycles were linked. Each longer wave may consists of two or three shorter cycles. This picture can be described by the periodic phase C2 or C3 in the CP regime of our model. The irregularity in long waves can also be explained by the chaotic regime CH. Our model gives a variety of possibilities of periodicity, multi-periodicity, and irregularity in economic history, although our data only show the chaotic pattern in monetary movements.

It is widely assumed that the long waves are caused by long lags, a belief coming from the linear paradigm (Rostow 1980). This condition is not necessary in our model, because the dynamic behavior of equation (4.5) depends both on $a\tau$ and $b\tau$. A strong overshooting plus a short-time delay has the same effect as a weak control plus a long-time delay, a similar point also made by Sterman (1985).

This model is so simple and general, it could have applications beyond the monetary system in the market economy we discussed here. For example, the growth cycles and long waves caused by overshooting and time delay may also happen in centrally planned economies.

4.4.6 Simulating empirical cycles

In comparing model-generated patterns with empirical data, we may confine our experiments to certain regions of the parameter space. For example, we can estimate the average period T from four times the decorrelation time T_d. The time delay τ in monetary control due to regulation lag and information lag is between 20 and 56 weeks (Gordon 1978). If we estimate the time delay τ to be 39 weeks, we can simulate SSM2 LL time series by the solution shown in Figure 4.13c, by setting $\tau = 39$, $a = 0.00256$, $b = 0.154$, and $\sigma = 0.0125$. The model results match well with major observed features, including the average amplitude A_m, decorrelation time T_d, positive maximum Lyapunov exponent λ, and correlation dimension D of the empirical SSM2 LL detrended time series.

The medium-term picture of simulated SSM2 LL in Figure 4.17 has well-behaved peaks and troughs with a stable period. We can hardly imagine that its long-term behavior is chaotic (see Figure 4.13c).

We tested the theoretical models with power spectra and autocorrelation analysis. The approximated period T of the chaotic solution can be estimated from T_d measured by three to five cycles. It is close to the fundamental period T_1 ($= f_{1-}{}^{1}$) determined by power spectra measured by 100 cycles with an error within 3 percent. For SSM2 LL time series, the difference of T_d and T_1 is less than 5 percent. We can obtain valuable information about the fundamental period T_1 without knowing the exact parameters of the deterministic model.

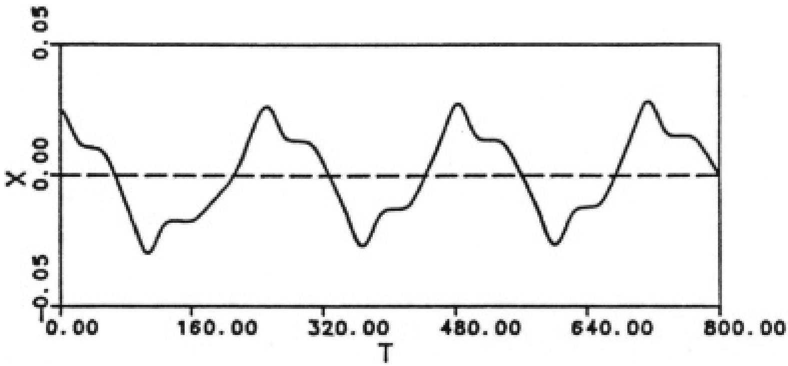


Figure 4.17 The time path of simulating SSM2 LL cycles, medium-term growth cycles.

4.4.7 Implication for forecasting and control policy

We should point out that the word *chaos* is misleading. Chaotic motion has both regular and irregular characteristics. We prefer to refer to continuous deterministic chaos as *imperfect periodic motion*, which has a stable fundamental period but an irregular wave shape and a changing amplitude. Actually, we may often recover more information from chaotic motion than from random movements. For example, econometric models based on linear stochastic processes mainly explain the variance of the residuals. They offer little information about the trend, phase, and periods of business cycles beyond the short term. We suggest a new forecasting approach based on detecting strangeness of growth cycles. Although the long-term prediction of the chaotic orbit is impossible from the view of nonlinear dynamics, a medium-term prediction of approximate period T can be made if we can identify strange attractors from the time series.

Let us discuss the meaning of the control parameters in equation (4.4). When $b = 0$, the monetary deviation from the natural rate will grow at a speed e^{at}. We define a characteristic doubling time t_a which measures the time needed to double the autonomous monetary expansion X(t) without control. Similarly, we can define a characteristic half time t_b, which measures the time needed to reduce the money supply to half its level when $a = 0$ and $X(t - \tau)$ reaches the control target $X_m = \frac{\sigma}{\sqrt{2}} = 1.4$ percent per year. The same is true for the contraction movements, since the feedback function G(x) is symmetric. Here $t_a = 5.2$ years and $t_b = 7.4$ weeks for SSM2 in our simulation. We see that even modest time delay and overshooting may generate cycles and chaos.

For policy considerations, we suggest that the fluctuations in money supply can be moderated by reducing the time delay τ or control parameter b. We can set $7.3 < \tau < 29.3$ weeks while fixing a and b; or let $29.5 < t_b < 108.7$ weeks (when $1.51 > b > 0.41$). These figures give a qualitative picture of monetary target policy which seems reasonable for the real economy.

4.5 Summary and discussion

Empirical evidence of low-dimensional strange attractors is found in log-linear detrended monetary aggregate data for the United States. These results are very encouraging, since new information is revealed about macroeconomic movements.

An one-dimensional delay-differential equation with only two parameters is suggested to describe monetary growth cycles. Self-generated periodic, multiperiodic, and chaotic behaviors are observed in the deterministic soft-bouncing oscillator model. This model sheds light on the mechanism of business cycles and long waves: the nonlinearity and time delay in feedback control may cause complex behavior. Although our model is simple and exploratory, it has enabled us to simulate the wave pattern and low dimensionality of monetary growth cycles.

We do not deny the complexity of social phenomena and the usefulness of disaggregated approaches in econometrics and system dynamics. Low-dimensional economic chaos is not only useful but also testable in economic studies. It can be understood through the experience of physicists. It is often convenient to introduce projection operators which decompose the system into one low-dimensional space, whose movements can be effectively simplified, and one orthogonal to it (Prigogine 1980). In practice, the right choice of the projection operator can only be made by empirical tests. Our work, together with previous efforts in study of complex systems, strongly supports the hope that social phenomena can be quantitatively described by simple mathematical models in some aspects. The key issues are which pertinent variables are to be observed and what can be learned from the model.

Three problems remain to be solved for future studies of economic chaos.

- The main obstacle in empirical analysis arises from limited data sources in economics. In order to facilitate the testing of deterministic chaos and to improve our understanding of modern economies, it is worthwhile to develop numerical algorithms that work with moderate and noisy data sets, as well as to expand the data base of economic statistics.
- The second question is how to determine the reference system. In our numerical experiment, the starting and ending periods of the observations were arbitrarily dictated by the available data. We do not know if the natural rate of growth is a constant or changing over time. Perhaps this problem can be solved by future testing on longer period combined with the effort of a historian helping to identify turning points of economic history. It is advantageous for nonlinear dynamics to introduce a time arrow or a historical perspective in analyzing complex systems (Prigogine 1980).
- The third issue is how to estimate parameters from empirical data. We should point out that the solutions of a nonlinear delay-differential equation may not be approximated by one- or two-dimensional discrete-time models in fitting the empirical data. We should be cautious in applying conventional technique of econometrics to chaos models.

Exploring economic chaos opens a new way to understand human behavior and social evolution. The studies of nonequilibrium and nonlinear phenomena have not only changed the techniques we use but also the ways in which we think (Prigogine and Stengers 1984).

Acknowledgments

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5 Searching for economic chaos

A challenge to econometric practice and nonlinear tests[1]

5.1 Introduction

Chaos research has attracted wide interest in the scientific community. Convincing empirical evidence has been found in fluid dynamics (Brandstater and Swinney 1987), chemistry (Argoul *et al.* 1987), and biology (Guevara *et al.* 1981). Relatively less convincing reports come from epidemiology, population dynamics, meteorology, and astronomy (Pool 1989). Positive evidence of continuous-time chaos in economic data has been published in our work (Chen 1987b, 1988a, b; Barnett and Chen 1987, 1988). But others only found some evidence of nonlinearity but weak or mixed results of low-dimensional deterministic chaos in discrete time (Brock and Sayers 1988; Scheinkman and LeBaron 1989). These works are still controversial.

Empirical studies of economic chaos began in mid-1980 (Chen 1984, 1987b; Sayers 1985, 1990; Brock 1986; Barnett and Chen 1987, 1988). Nonlinearity (Ashly *et al.* 1986; Brock and Sayers 1988; Scheinkman and LeBaron 1989), non-normality (Ashly *et al.* 1986), and non-independence (Brock *et al.* 1987; Hsieh 1989) in economic time series is widely discovered. Negative or “mixed” findings of economic chaos are also reported (Sayers 1985, 1990; Brock and Sayers 1988; Frank and Stengos 1988; Frank *et al.* 1988). Only little evidence of chaos is found in monetary indexes (Chen 1987b, 1988a, b), daily stock returns (Chen 1984; Scheinkman and LeBaron 1989), and laboratory simulations (Sterman *et al.* 1989). There is a fierce debate about the empirical findings of economic chaos (Chen 1988b; Brock and Sayers 1988; Ramsey *et al.* 1990).

In this chapter I will first introduce some of the techniques for distinguishing between randomly generated data and data generated by deterministic processes. I then analyze pitfalls in statistical tests designed to detect chaos. My work on monetary aggregates serves an example to discuss the problem of inference with economic time series and illustrate the usefulness of the continuous-time model. This model is just sufficient to generate behavior that closely resembles the data.

5.2 Distinguishing between deterministic and stochastic processes

There are at least four possible candidates for describing fluctuating time series: linear stochastic processes, discrete-time deterministic chaos, continuous-time deterministic chaos, and nonlinear deterministic chaos plus noise. Testing and modeling the last one is only in its infancy, because a high level of noise will easily destroy the subtle signal of deterministic chaos. We discuss the first three candidates here and give numerical examples of white noise and deterministic chaos as the background for further discussions. They include the linear autoregressive AR(2) model, the logistic chaos model in discrete time (LCD thereafter) widely used in population studies and economics, and the Rössler (1976) model of deterministic chaos in continuous time (RCC thereafter).

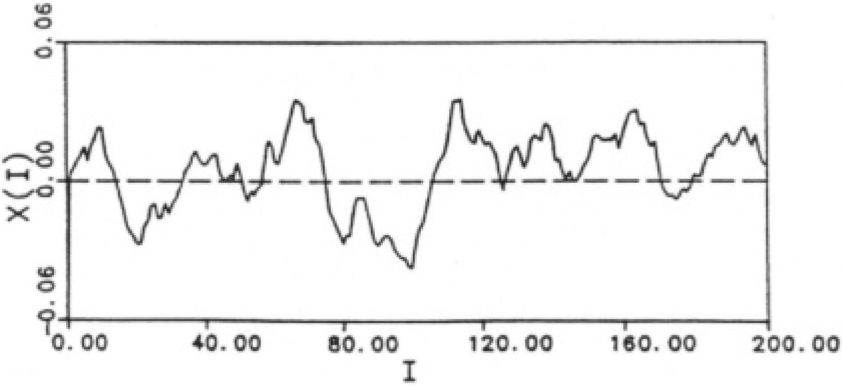
Sample time sequences of these models are shown in Figure 5.1. They all exhibit irregular economic fluctuations like economic data very much when appropriate scales are used. However, a closer examination reveals differences among them.

How can we distinguish between such different theoretical specifications? Can we tell if a given economic time series is generated by one of them? These are the basic questions we shall discuss. Four main tools are available, the "phase portrait," the autocorrelation function, the Lyapunov exponent, and the fractal dimension. I shall describe them briefly in turn.

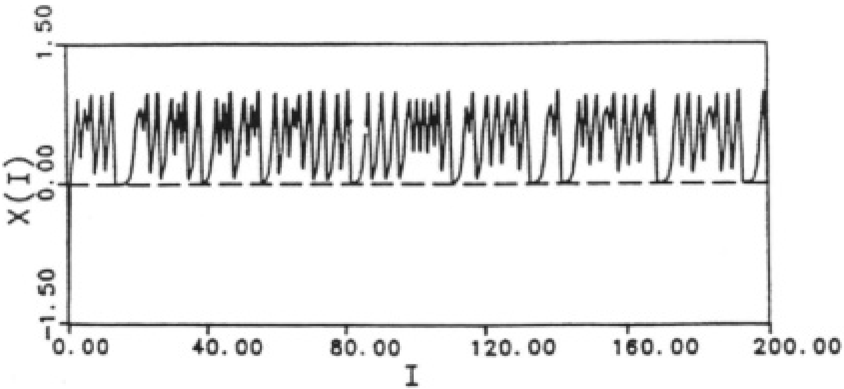
5.2.1 Phase space and phase portrait

From a given time series X(t), an m-dimensional vector V(m, T) in phase space can be constructed by the m-history with time delay T: $V(m, T) = \{X(t), X(t + T), \ldots, X[t + (m - 1)T]\}$, where m is the embedding dimension of phase space (Takens 1981). This is a powerful tool in developing numerical algorithms of nonlinear dynamics, since it is much easier to observe only one variable than to analyze a complex multi-dimensional system.

The phase portrait in two-dimensional phase space X(t + T) versus X(t) gives clear picture of the underlying dynamics of a time series. Figure 5.2 displays the phase portrait of the three models using the sample data of Figure 5.1. The nearly uniform cloud of points in Figure 5.2a closely resembles the phase portrait of random noise (with infinite degree of freedom). The curved image in Figure 5.2b is characteristic of the one-dimensional unimodal discrete chaos LCD with a fractal dimension less than one. The spiral pattern in Figure 5.2c is typical of a RCC strange attractor whose dimensionality is a fractal number between two and three. Its spiral orbit differs from periodic cycles.



(a)



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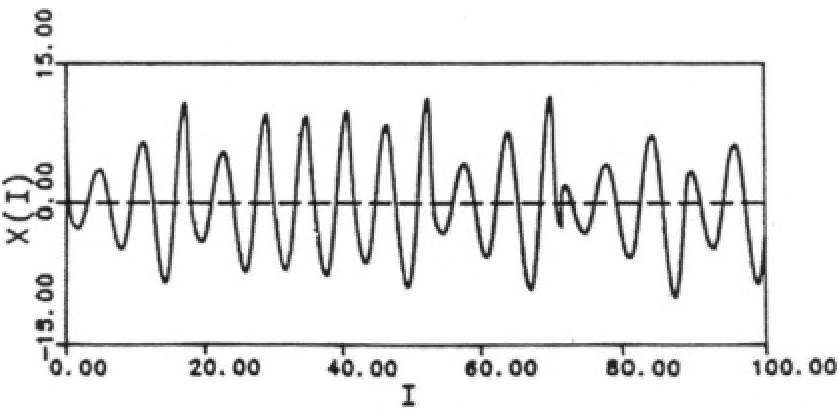
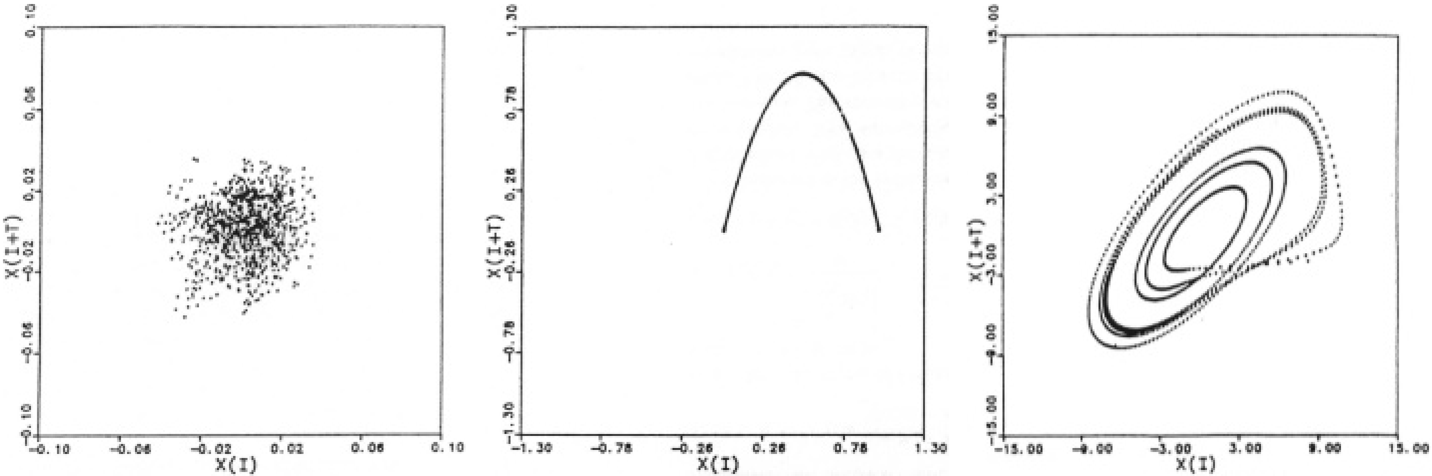


(c)

Figure 5.1 The seemingly erratic time series of linear and nonlinear models (the same as Figure 4.1). (a) AR(2). (b) LCD. (c) RCC.



(a) (b) (c)

Figure 5.2 The phase portraits X(I) vs. X(I + T) of three models in Figure 5.1 or 4.1. (a) AR(2). (b) LCD. (c) RCC.

5.2.2 Long-term autocorrelations

The autocorrelation function is another useful concept in analyzing time series. The autocorrelation function AC(I) is defined by

$$AC(I) = AC(t'-t) = \frac{COV[X(t'), X(t)]}{E[X(t)-M)^2]}$$

where M is the mean of X (t) and COV [X(t′), X(t)] is the covariance between X(t′) and X(t). The autocorrelation function of stochastic processes (Figure 5.3), such as an AR(2) process, decay quickly to irregular oscillations; the autocorrelations of discrete-time chaos, such as LCD, look like that of random noises. In contrast, the autocorrelation function of continuous-time chaos, such as that of RCC, shows wave-like oscillations with smooth decay.

5.2.3 The numerical maximum Lyapunov exponent

Chaotic motion is sensitive to initial conditions. This sensitivity is measured by the Lyapunov exponents. Consider a very small ball with radius $\varepsilon_i(0)$ at time t = 0 in the phase space. The length of the i-th principal axis of the ellipsoid

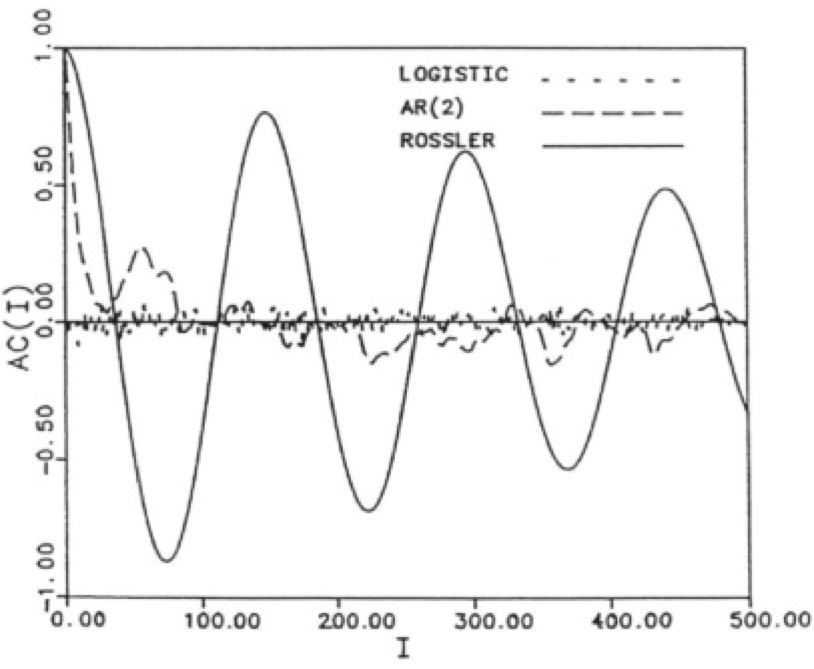


Figure 5.3 The autocorrelations of the three models in Figure 5.1 (same as Figure 4.1) including AR(2), LCD, and RCC.

evolved from the ball at time t is $\varepsilon_i(t)$. The spectrum of Lyapunov exponents λ_i from an initial point can be obtained theoretically by (Farmer 1982)

$$\lambda_j = \lim_{t\to\infty}\lim_{\varepsilon(0)\to 0}\left\{\frac{\ln[\varepsilon_j(t)/\varepsilon_j(0)]}{t}\right\}$$

The maximum Lyapunov exponent λ (the largest among λ_i) can be calculated numerically by the Wolf algorithm (Wolf *et al.* 1985). Its limiting procedure is approximated by an averaging process over the evolution time EVOLV. This algorithm is applicable when the noise level is small. The maximum Lyapunov exponent λ□ is negative for stable systems with fixed point, zero for periodic or quasiperiodic motion, and positive for chaos. The largest Lyapunov exponent plays an important role in characterizing deterministic dynamics in theoretical studies. It has rather limited use in empirical tests, since random noise may also generate a positive exponent numerically. However, the maximum Lyapunov exponent may reveal some clue of chaos, if the order of λ^{-1} is about T_d the decorrelation time (Nicolis and Nicolis 1986). If one has any doubt about the possibility of random noise, we recommend to check the phase portrait and to compare the reverse of the Lyapunov exponent with the decorrelation time. These techniques can tell whether business cycles are likely generated by unit-root random process or chaos (Nelson and Plosser 1982; Frank and Stengos 1988; Sayers 1990).

5.2.4 The correlation and fractal dimensions

The most useful characteristic of chaos is its fractal dimension (Grassberger and Procaccia 1984) which provides a lower bound to the degrees of freedom for the dynamic system. The popular Grassberger–Procaccia (GP hereafter) algorithm estimates the fractal dimension by means of the correlation dimension D (Grassberger and Procaccia 1983). The correlation integral $C_m(R)$ is the number of pairs of points in m-dimensional phase space, whose distance between each other is less than R. For random or chaotic motion, the correlation integral $C_m(R)$ may distribute uniformly in some region of the phase space, and it has a scaling relation of R^D. Therefore, we have

$$\ln_2 C_m(R) = D\ln_2 R + const$$

For white noise, D is an integer equal to the embedding dimension m. For deterministic chaos, D is less than or equal to the fractal dimension.

5.3 Pitfalls in statistical testing for chaos

In addition to the difficulties just mentioned, there are two major pitfalls in testing empirical data for chaos that need to be recognized. These involve (1) the common problems caused by insufficient information in empirical tests; (2) the specific limitations of statistical inference for distinguishing chaotic from stochastic processes.

5.3.1 The discrepancy between mathematical theory and numerical experiment

In any scientific discipline, mathematical theory only approximates some aspects of empirical phenomena. Certainly, more difficulties attend empirical work than theoretical study, since real world is much more complex than simplified models. This is especially true for studies of nonlinear dynamics. I now want to outline about some of these difficulties in detecting chaos from empirical data.

5.3.1.1 Sparse data

Typical experiments in physics, chemistry, and biology often collect tens of thousands to almost million data points and sampling time usually cover more than 100 cycles. However, most economic indicators have only several hundred data points covering only a few cycles. This deficiency prevents many of the powerful tools in nonlinear dynamics, such as the Poincáre return map, spectral analysis, mutual information, saddle-orbit analysis, and others based on statistical theory, from detecting intrinsic irregularity even when it is there.

Some algorithms give useful hints even for a small data set, but their power is much reduced. Worse, they may generate numerical artifacts. For example, the autocorrelations of continuous-time chaos models in numerical models show exponential decay when the time span is very large (Grossmann and Sonneborn-Schmick 1982). However, the autocorrelations of continuous-time chaos look like those of periodic movements when only a few cycles of data are available (Figure 5.3). Econometricians often concern that small data sets may introduce spurious low frequency in the power spectrum when there are only about hundreds of data points available (Nelson and Kang 1981). We found out the opposite possibility that first differencing detrending may introduce spurious random image and leave out possible nonlinear cycles.

The problem of sparse data is especially acute in dimension calculations because their data requirements are severe. The minimum number of data points N_D required in dimension estimation has an exponential relation with the underlying dimension D, i.e., $N_D = h^D$, where h varies with different attractors (Mayer-Kress 1986). For example, in the case of the Mackey-Glass model (Mackey and Glass 1977), the required data for $D = 2$ is $N_D > 500$ points; and that for $D = 3$ is $N_D > 10{,}000$ points (Kostelich and Swinney 1989). We also investigate the effect of the sample rate in dimension calculation. Generally speaking, 10–100 points per cycle are needed for the Mackey-Glass model. The relative error of numerical correlation dimension is about 1 percent for 100 cycles, 3 percent for 30 cycles, 8 percent for 10 cycles, and 18 percent for only five cycles. Econometric tests often ignore the issue of sampling rate because economic theory commonly assumes away of periodic motion except for seasonal changes.

It is also found that a discrete map needs even more data points than a continuous flow. For instance, the reasonable number of data points is 5000 for Henon attractor (Henon 1976) with $D = 1.26$ (Ramsey and Yuan 1989). As a rule of thumb, the observed dimensionality in empirical data cannot be higher than five and embedding dimension in calculation should not be larger than ten, when data size is less than 10,000. For example, two tests of correlation dimension were conducted with quarterly US real GNP and unemployment at embedding dimension of 20 with only 134 observations (Brock 1986; Brock and Sayers 1988). Estimated dimension for US unemployment rate was between 2.5 and 3.5. This is a common error in econometric tests, when people ignore the exponential nature of fractal geometry.

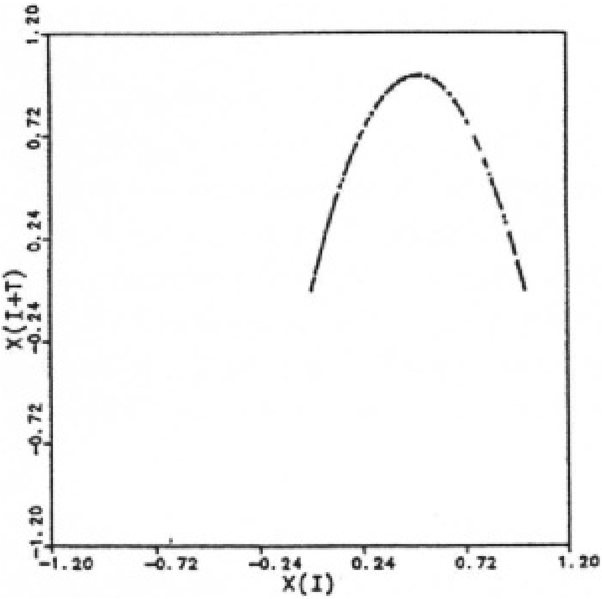
5.3.1.2 Noise

The second major problem is that the subtle information of deterministic chaos can be contaminated by numerical or measurement noise. The question is to what degree can noise be tolerated in empirical tests? There are several numerical tests in terms of uniform noise. For example, it is found that the phase portrait of the noisy Henon map can be recognized and the correlation dimension can be estimated when random jitter is chosen from [–0.05, 0.05], the up-bond of noise/signal ratio is 0.1 percent for correlation dimension of the Mackey–Glass model (Ben-Mizrachi *et al.* 1983). In estimating the largest Lyapunov exponent, the allowance is 5 percent (Wolf *et al.* 1985).

5.3.1.3 Continuous and discrete time and the time unit

For qualitative models in economic theory, the choice between difference and differential equations is a matter of a mathematical convenience or aesthetic taste. For empirical models, however, the choice of time scale can crucially affect estimation and verification. Preferably, it should be determined by the dynamic nature of the process under investigation. For example, in population dynamics, the period of reproduction of non-overlapping generation insects can be used as the natural unit to construct a difference equation. More general systems that exhibit continuous motion with a natural or intrinsic period should be sampled at intervals that correspond with the intrinsic frequency. The resulting discrete time series can then be described by a difference equation. However, when the natural period of a process is not known, the choice of time unit is an open question. We cannot arbitrarily choose the time unit without theoretical analysis and empirical evidence. This would appear to be the view point we should take in economics as noted by Koopmans. He suggested replacing the discrete-time stochastic model with a continuous-time stochastic model when the serial correlation is much longer than the time unit (Koopmans 1950).

Figure 5.4 shows the different patterns of discrete-time and continuous-time chaos with varying time lag. Figure 5.5 shows that the pattern of the phase portrait is sensitive to the time lag T for discrete Mapping, but not sensitive for continuous-time ones. The latter only changes its shape with varying T (Figure 5.4c, d). In either case, the time unit plays a critical role in revealing underlying dynamical mechanisms of time series.



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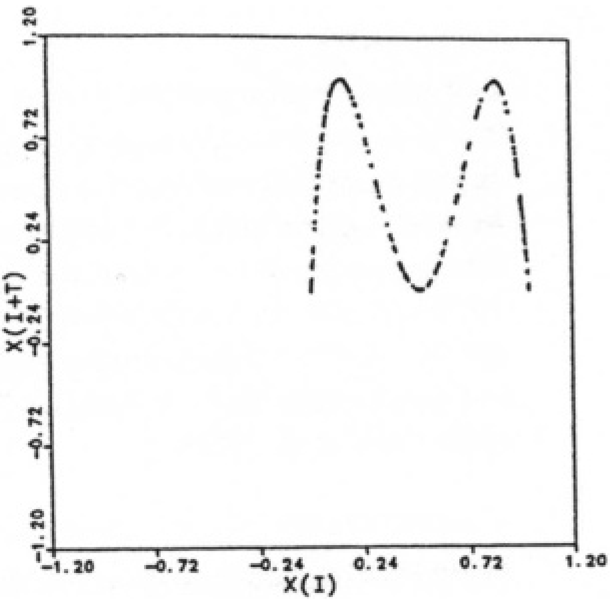
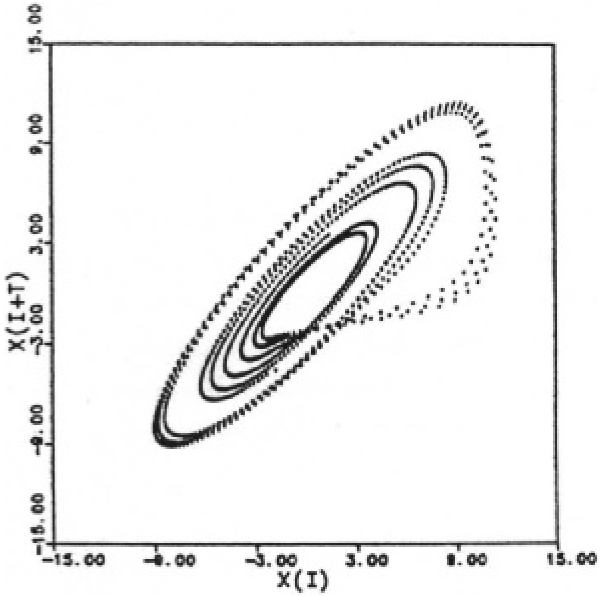


(b)

Figure 5.4 The two-dimensional phase portrait of deterministic chaos with varying time lag T. (a) LCD, T = 1. (b) LCD, T = 2. (c) RCC, T = 0.5. (d) RCC, T = 1.



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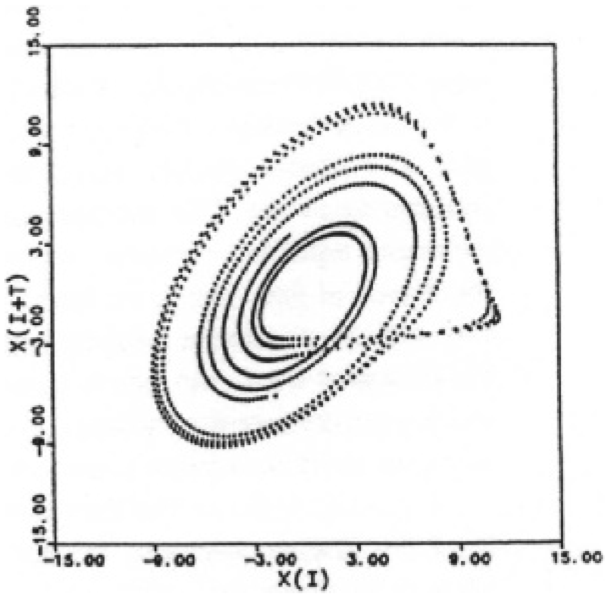


(b)

Figure 5.4 Continued.

To illustrate the problem, consider a discrete-time Henon model economy and assume the intrinsic unit is a month. Now look at the phase portrait for "quarterly" or "annual" samples. The phase portraits in Figure 5.5 show that the pattern of quarterly data is more complex than that of monthly data. It also illustrates that the image of the annual data appears like random noise except its square boundary. Fitting the Henon model to quarterly and annual data leads to complete failure. This example illustrates why, if the underlying economic dynamics are truly discrete and its intrinsic time unit is the order of month, then the quarterly or annual economic indicators are not capable of revealing the discrete nature of dynamic process.

Numerical experiments show that the autoregressive and moving average model (ARMA) can well represent data generated by discrete-time chaos, such as the Henon and logistic models when the time intervals are the intrinsic ones but not when they are based on a sample at time intervals different from this. For continuous- time models, like those of Lorenz (1963) or Mackey–Glass (Mackey and Glass 1977), the ARMA model can fit the generated data only when the sampling time interval is roughly of the same order of the average orbital time. In either case, success or failure in fitting ARMA model cannot tell whether the data are generated by noise or chaos.

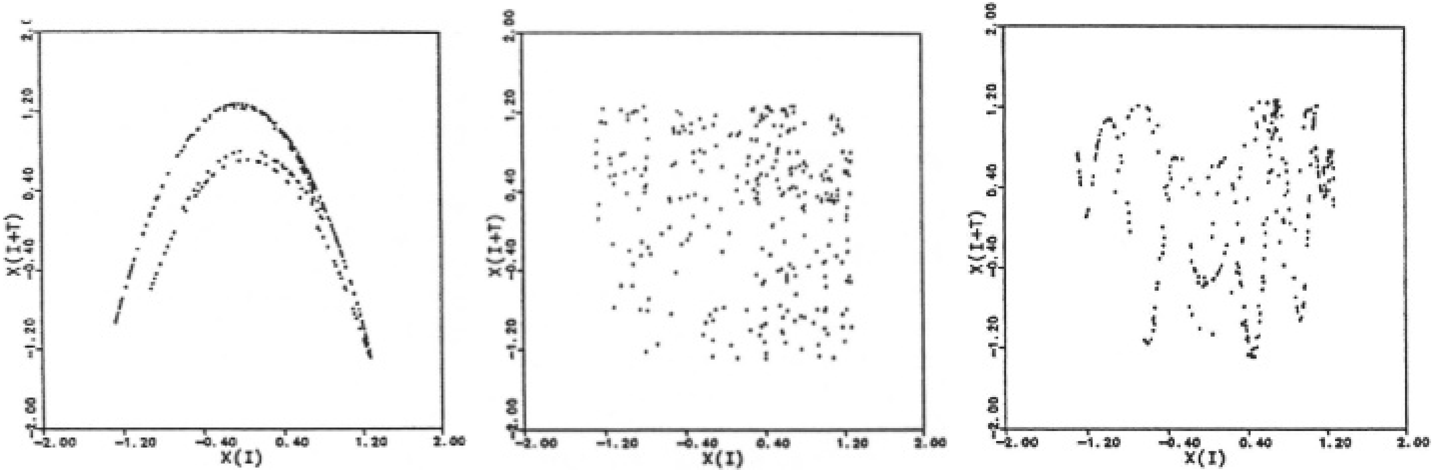
Spectral analysis and auto-covariance function cannot distinguish between discrete-time chaos and random noise (Dale 1984; Brock 1986). However, these methods can identify continuous-time chaos (Crutchfield *et al.* 1980; Grossman and Sonneborn-Schmick 1982; Nicolis and Nicolis 1986). Few economic researchers are aware of these differences.

5.3.2 Limitations of statistical inference

Statistical inference has been developed to test stochastic process with identical independent distribution (i.i.d.). To what degree statistical inference is capable to deal with chaotic process is still an open question. Stochastic and chaotic process is polar models based on conflicting assumptions. Most empirical cases lie in the gray zone between chaos and noise. Econometricians will be soon aware of the gap between the static nature of statistical inference and the dynamic complexity of chaotic behavior.

5.3.2.1 Inseparability of nonlinear systems

Currently, econometric reasoning is based on linear stochastic models. Therefore, interacting components can be separated and analytical solutions can be obtained in linear systems, because the superposition principle of linear systems mathematically justifies the theoretical framework of homogeneous and additive economies. However, the superposition principle is not valid for nonlinear systems, since the whole is more than the sum of the parts for nonlinear dynamics. Nonlinear dynamic equations rarely have closed form of analytical solution. This situation casts serious doubt to regression exercise for nonlinear dynamic



(a) (b) (c)

Figure 5.5 The phase portrait of the Henon economy observed from varying time unit. (a) t = 1. (b) t = 2. (c) t = 12.

problem. Nonlinearity imposes a great challenge to time series analysis in economic studies.

The inseparability of nonlinear components may frustrate econometricians when they are developing statistical tools for testing economic chaos. For example, Brock argues that chaotic time series can be detected by using a linear filter such as first differencing, or taking residual of a fitted ARMA model. He believes that the dimensionality of the original and the filtered time series should be the same (Brock 1986). However, it is difficult to judge the result of the differencing operation because it is sensitive to the time interval of differencing. The concept of fractal dimensionality comes from self-similarity of fractal structures (Hentschel and Procaccia 1983). Brock did not discuss the issue of self-similarity when he tried to prove the residual test theorem.

The complexity of the problem can be seen from a special case of first differencing. Assume $\{X(t)\}$ denotes the continuous-time series generated from a strange attractor, say, the Rössler attractor. The fractal dimension of Rössler attractor D is larger than two but less than three. A one-dimensional chaotic discrete-time series $\{u_n\}$ can be obtained from the Poincáre section of $\{X(t)\}$ in a two-dimensional phase space. Its time interval is equal to the averaging orbital (natural) time T_N of the attractor (see Figure 5.6). Therefore, the fractal dimension D' of $\{u_n\}$ must be less than 1.

For the differenced time series $\{u_n\}$, the outcome is uncertain if the time interval for differencing is arbitrarily chosen. In practice, the differencing procedure in econometric modeling is a "whitening" process that cuts off the autocorrela-

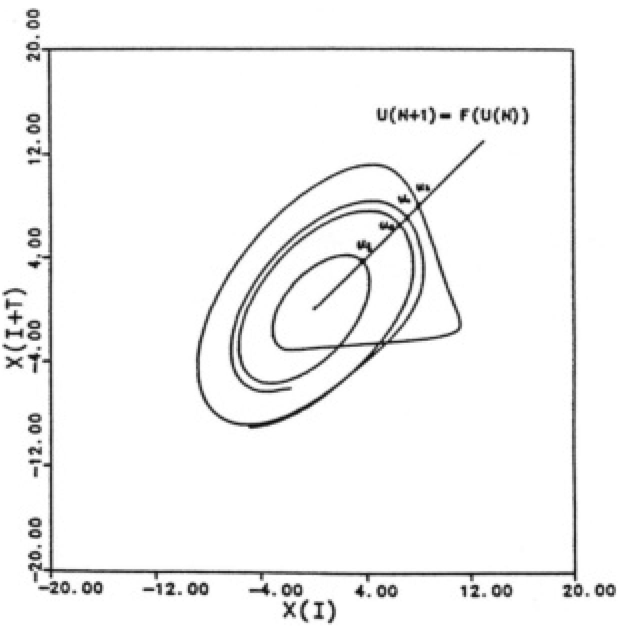


Figure 5.6 The relationship between continuous-time and discrete-time chaos.

tion and increases the variance in observed time series. So far as we know, there is no theoretical argument and numerical evidence to show the invariance of dimensionality under a difference transformation.

5.3.2.2 Changing strangeness under the residual test

It has been noted that correlation dimension is not invariant to a smooth coordinate transformation (Ott *et al.* 1984). The residual of a moving average process introduces random noise into the original data. This procedure may erase the fractal structure (Garcia-Pelayo and Schieve 1991). For the autoregressive process, the situation becomes more subtle. The metric fractal dimension under a smooth linear deterministic transformation is invariant, but most probability dimensions are not.

To check the validity of the residual test, we tested the Henon attractor with 5000 data points which is good enough to uncover its dimensionality (Ramsey and Yuan 1989). We fit the ARMA (6,3) model and AR(6) model respectively to the Henon time series. The correlation dimension of ARMA (6,3) residuals is equal to the embedding dimension, which is the characteristic of random noise. The correlation dimension of AR(6) residuals cannot be determined because no parallel line can be identified from GP plot. Probably, the AR(n) transformation changes the probability density in phase space, and the definition of correlation dimension is related to the square of probability density (Hentschel and Procaccia 1983). A residual test of the logistic time series has a similar result. For a continuous-time model, such as the Lorenz attractor, fitting it to the low-order ARMA model is increasingly difficult, when autocorrelation is long and the time interval is short compared with its natural orbital time. No clear-cut conclusion can be reached from the residual tests in our numerical experiment.

A technical remark should be made here. It is known that only idealized models of pure random noise and well-behaved attractors have well-defined correlation dimension. This means that a time series may not have a well-defined correlation dimension. When no plateau region or no saturated dimension can be identified from the Grassberger–Procaccia plots, the correlation dimension is not tractable. The face value of the numerical mean in dimension calculations should not be readily accepted until its Grassberger–Procaccia plot has been carefully examined.

5.3.2.3 The pitfall of linear stochastic filter in detecting deterministic chaos

It is well known that any Gaussian or i.i.d. (identical independent distribution) time series can be represented by an infinite autoregressive process or moving average process (Granger and Newbold 1986). Some features observed in empirical tests, such as the long autocorrelations in a deterministic time series, can be simulated by a finite-order stochastic process, either in linear or nonlinear form. But a stochastic model cannot simulate a self-similar structure like that of the

Cantor set. Characterizing a strange attractor requires a spectrum with infinite dimensionality (Farmer *et al.* 1983).

The above discussion may help to solve the dispute raised by Ramsey, Sayers, and Rothman. Conflicting results from nonlinear diagnostics and the residual test are reported in testing the monetary indexes (Chen 1987b, 1988b; Barnett and Chen 1988; Ramsey *et al.* 1990). Ramsey and his co-workers duplicated our results from log-linear detrended data. However, there is no sign of nonlinear structure in the residuals resulted from a double-sided moving average filter. The reason for the absence of such a sign is that the symmetric, low-reject filter used by Ramsey and his colleagues did not wipe out high-frequency noise, but improperly removed the low-frequency deterministic components. As we indicated before, a continuous-time chaos can be considered as an imperfect periodic motion with low frequency and irregular amplitude (Chen 1988b). In Ramsey's test, the filtered time series did not even become stationary, which was required by attractor modeling. The low-reject filter made the variance of the filtered monetary index increase over time. The seemingly contradictory reports resulting from the residual tests are actually an aid in understanding the essential difference between linear stochastic deduction and nonlinear deterministic logic.

5.3.2.4 The roots of non-stationality and non-normality

Non-stationality and non-normality are widely observed in economic time series because economies are open systems. It is a formidable task for econometricians to deal with these problems within the conventional framework of i.i.d. process. Deterministic approach and stochastic approach in theoretical economics represent conflicting ideas of endogenous and exogenous mechanism of business fluctuations. However, the deterministic description and probabilistic description of dynamic process in theoretical physics are simply complementary tools in the unified dynamical framework. For example, chemical reactions can be described by (deterministic) differential equations or a master equation. The probability distribution function in master equation can be obtained by solving a (deterministic) partial differential equation. In the case of the Fokker–Planck equation, the peak of the distribution function or the mean value evolves along the path that can be represented by the trajectory of the corresponding deterministic equation. Therefore, these two approaches are equivalent when the distribution function is unimodal (Nicolis and Prigogine 1977, 1989; Reichl 1980). However, during bifurcation at the critical point of some control parameter, fluctuations will be so large that the mean value no longer represents the most-likely situation because the distribution function may become multi-humped (Baras *et al.* 1983; Chen 1987a). Actually, many statistical practitioners have already observed non-normal, long-tail, and multi-modal distribution in empirical studies. The relationship between deterministic approach and probabilistic approach in nonlinear dynamic systems is illustrated in Figure 5.7.

Roughly speaking, between two bifurcation points, the dynamic process follows a deterministic path, which can be described by averaging when the

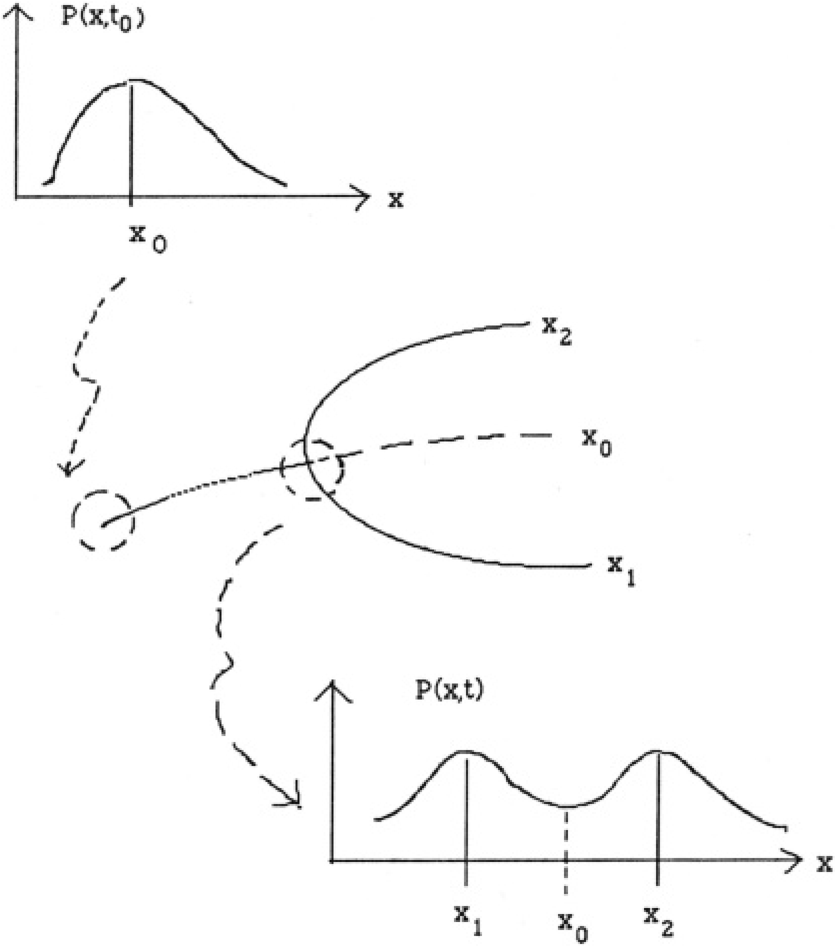


Figure 5.7 The relationship between stochastic equation and deterministic equation.

process has a unimodal distribution. Statistic inference or i.i.d. process can be approximately applied only in this situation. Bifurcation model is quite useful in understanding non-continuity, non-stationality, and non-normality in real economies when econometricians are confounded by the multiple phase character of economic evolution (Day and Water 1989). Changing economies can be one of the major obstacles in detecting economic chaos.

5.3.2.5 Some conclusions about numerical algorithms

Practically, we can only have some clue of low-dimensional attractors with finite data sets. There is no way to identify deterministic chaos with certainty.

At present, with data only in the hundreds, the discovery of economic strange attractors whose dimensionality is higher than three is unlikely.

We can only speculate why we were unable to identify correlation dimensions for other types of economic time series, such as GNP, IPP, and the Dow-Jones index, in our numerical tests. Either their dimensions are too high, or their noise levels are too large, or they do not in fact reflect intrinsic characteristics of complex behavior, or changing economies caused by series of bifurcations. Current observational scope and analytical technique are not capable to solve these problems.

5.4 Testing economic chaos in monetary aggregates

With the pitfalls well in mind, I shall briefly reconsider my work on monetary aggregates to illustrate techniques for detecting chaos. Federal Reserve's monetary indexes include M1, M2, M3, and L. These are simple-sum aggregate indexes (denoted by SS plus monetary index hereafter). There are also parallel Divisia theoretical indexes such as Divisia demand indexes (denoted by DD plus monetary index hereafter) and Divisia supply indexes (denoted by DS plus monetary index hereafter).

We tested 12 types of monetary index time series covering the period from 1969 to 1984. Five of them suggested strangeness: Federal Reserve's simple-sum SSM2, Divisia demand DDM2, DDM3, DDL, and Divisia supply DSM2 monetary aggregates (Chen 1987b, 1988a, b). The behaviors of Divisia aggregates are very similar. We only discuss SSM2 and DDM2 here for brevity. Previously, the weekly data were used in our test. Now, the tests of the original monthly data are added here. Our data source is Fayyad (1986). Monthly and weekly indexes are distinguished by the letter m and w respectively. All the data are log-linear detrended, since no strange attractors have been identified from the first differencing data.

5.4.1 Data processing and path smoothing

Ramsey and his co-authors noted that the weekly monetary data used in our previous test were largely generated from monthly raw data by spline interpolation and model reconstruction (Ramsey *et al.* 1990). The question is whether the interpolation procedure may introduce additional correlation or alter the original dimensionality. For this reason, we re-examined the original monthly monetary data. The numerical results of correlation dimension n, decorrelation time T_d, and the largest Lyapunov exponent l of the monthly data are essentially in the same order as weekly data. It is not surprising that interpolation does not change the primary characteristics of continuous-time deterministic movements in our case. The interpolation procedure is equivalent to a smoothing technique for noise reduction.

In fact, interpolation is widely used in the scientific community when raw data is incomplete (Charney *et al.* 1969; Tribbia and Anthes 1987). Interpolation and smoothing were also used in testing chaos from climate, ecological, and epidemic time series (Grassberger 1986; Schaffer 1984; Schaffer and Kot 1985).

5.4.2 Detrending methods and attractor models

Testing economic aggregate time series for chaos or randomness is a formidable task. The intrusion of growth trends raises a critical problem of how to characterize a growing economy by means of mathematical attractors. Various methods of detrending have been used in econometrics. We are interested in their theoretical implication: the choice of reference system in observing economic behavior. We attempted to explore this problem through numerical experiments on empirical data.

For example, the percentage rate of change and its equivalent form, the logarithmic first differences, are widely used in fitting stochastic econometric models (Osborne 1959; Friedman 1969). It can be defined as follows:

$$Z(t) = \ln S(t+1) - \ln S(t) = \ln\left[\frac{S(t+1)}{S(t)}\right]$$

where S(t) is the original time series, and Z(t) is the logarithmatic first difference. This method is also called difference-stationary in econometric literature.

An alternative method called log-linear detrending has been used in chaos models (Dana and Malgrange 1984; Brock 1986; Barnett and Chen 1988). We have

$$X(t) = \ln S(t) - (k_0 + k_1 t)$$

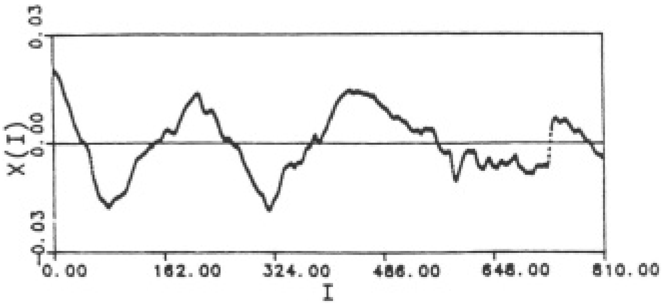
or

$$S(t) = S_0\, e^{k_1 t}\, e^{X(t)}$$

where S(t) is the original time series, and X(t) is the resulting log-linear detrended time series, k_0 is the intersection, k_1 the constant growth rate, and S_0 = exp (k_0). This method is called trend-stationary in econometrics.

Our numerical experiments indicate that the percentage rates of change are whitening processes based on short-time scaling. Log-linear detrending, on the other hand, retains the long-term correlations in economic fluctuations, since its time scale represents the whole period of the available time series. Findings of evidence of deterministic chaos mainly from log-linear detrended economic aggregates lead to this conclusion.

Figure 5.8a shows the time sequences of the log-linear detrended (denoted by LL) monetary aggregates SSM2. Their almost symmetric pattern of nearly equal length of expansion and contraction is a typical feature of growth cycles in economic systems. The usual business cycles are not symmetrical. Their longer expansions and shorter contractions can be obtained in such a way, when a trend with constant growth rate is adding to symmetric growth cycles. The logarithmic



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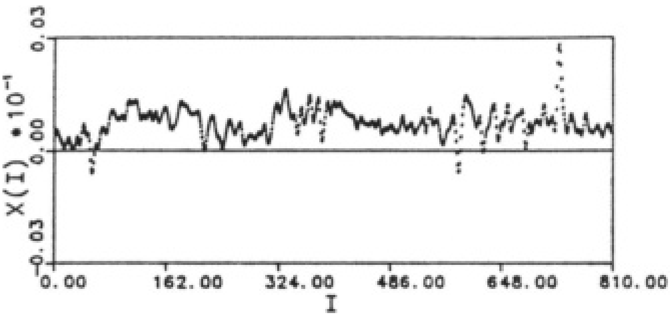


(b)

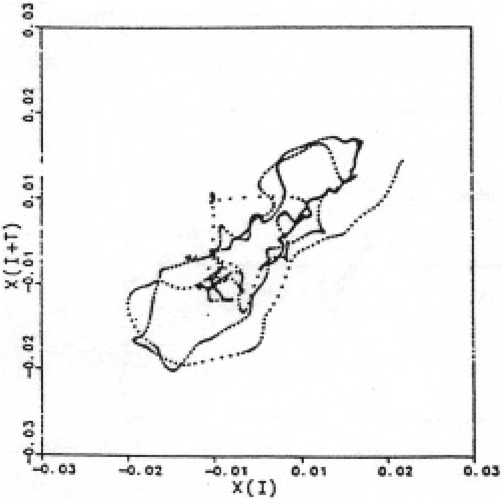
Figure 5.8 Comparison of the detrended weekly time series. (a) SSM2 LL series. (b) SSM2 FD series.

first difference time series (denoted by FD) SSM2 is given in Figure 8b as a comparison. The latter is asymmetric and more erratic.

5.4.3 Empirical evidence of deterministic and stochastic processes

Based on the phase portrait and autocorrelation analysis, we can qualitatively distinguish a stochastic process from a deterministic one. Figure 5.9a presents the phase portrait of detrended monetary aggregates SSM2 LL. It rotates clockwise like the spiral chaos in Figure 5.2c. The complex pattern is a potential indication of nonlinear deterministic movements, which eliminates the possibilities of white noise or simple periodic motions. To compare with a series that appears like white noise, the phase portrait of IBM daily stock returns is shown in Figure 5.9b. The autocorrelations of the detrended time series are shown in Figure 5.10. Readers may compare these with the autocorrelations in Figure 5.3.

If we approximate the fundamental period T_1 by four times the decorrelation time T_d, as in the case of periodic motion, then, T_1 is about 4.7 years for SSM2 LL. This result is very close to the common experience of the averaging length of US business cycles. We will return to this point later.



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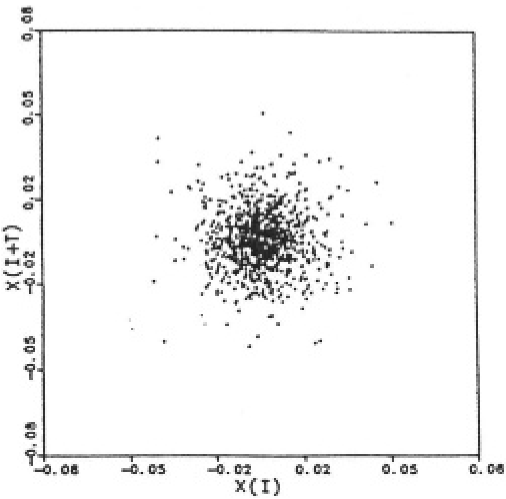


(b)

Figure 5.9 Comparison of the phase portraits of empirical time series. (a) SSM2 LL series. (b) IBM daily return series.

5.4.3.1 The numerical maximum Lyapunov exponent and autocorrelations

Let us now consider the tests using the Lyapunov experiments and autocorrelations. In theory, the choice of evolution time EVOLV, embedding dimension m and time delay T has no relevance to the maximum Lyapunov exponent.

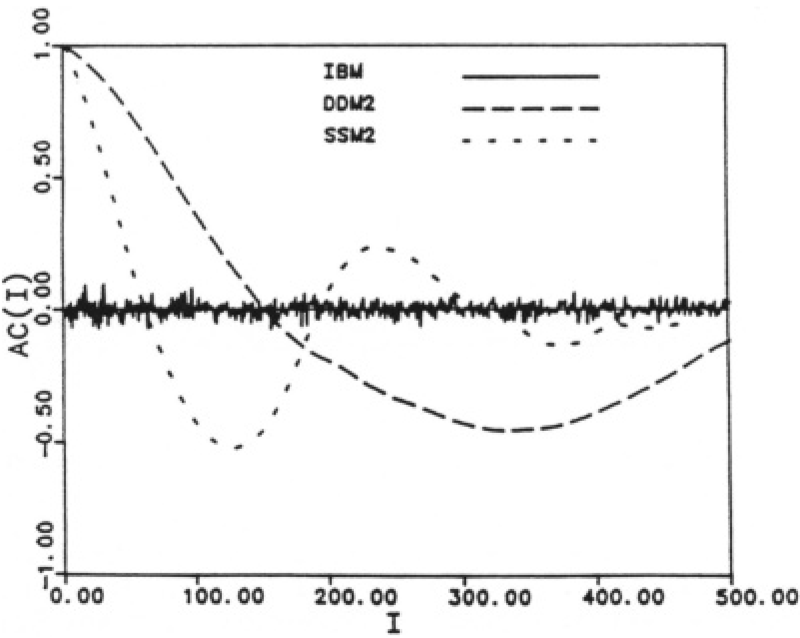


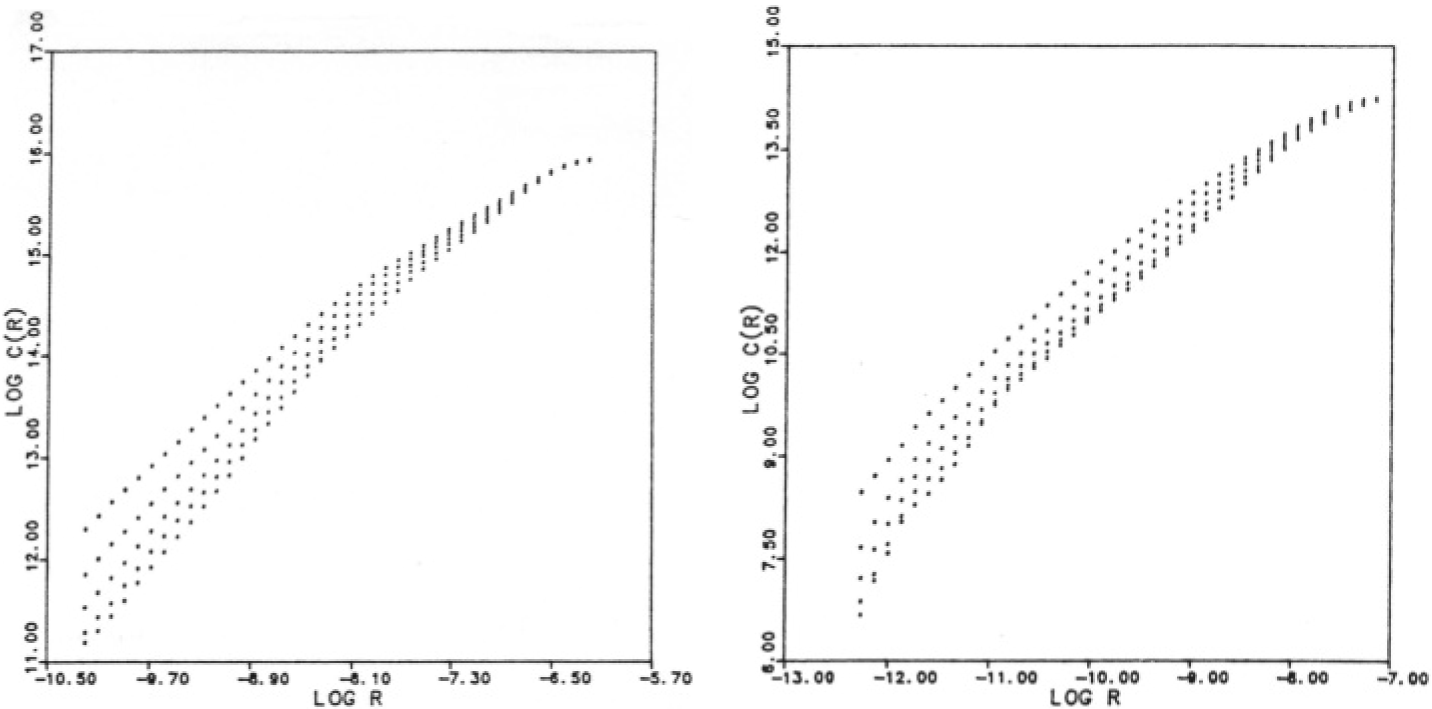
Figure 5.10 Comparison of autocorrelation functions of IBM daily returns, DDM2 LL, and SSM2 LD series.

In practice, the value of Lyapunov exponent does relate to the numerical parameters. The range of evolution time EVOLV must be chosen by numerical experiments. The positive maximum Lyapunov exponents of the investigated monetary aggregates are stable over some region in evolution time. The numerical Lyapunov exponent is less sensitive to the choice of embedding dimension m. In our tests, we fixed m at five and time delay T at five weeks based on the numerical experiments. For example, the stable region of EVOLV is 45–105 weeks for SSM2 and 45–150 weeks for DDM2. Their average maximum Lyapunov exponent l over this region are 0.0135 and 0.0184 (bit per week), respectively.

The characteristic decorrelation time T_d of the SSM2 LL is 61 weeks or 1.2 years. The reciprocal of the maximum Lyapunov exponent λ^{-1} (= 74.1 weeks or 1.4 years) for SSM2 LL is roughly of the same order of magnitude as the decorrelation time T_d. This relation does not hold for pure white noise.

5.4.3.2 The correlation dimension

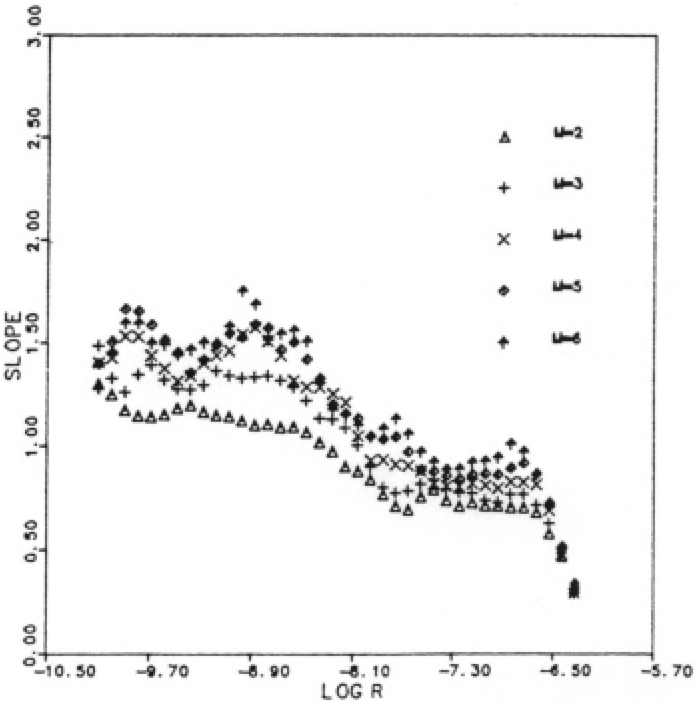
The correlation dimension can be estimated by the Grassberger–Procaccia algorithm. Plots of ln $C_m(R)$ versus ln R and slope versus log R for SSM2 LL and DDM2 LL are shown in Figure 5.11 and Figure 5.12. The existence of linear



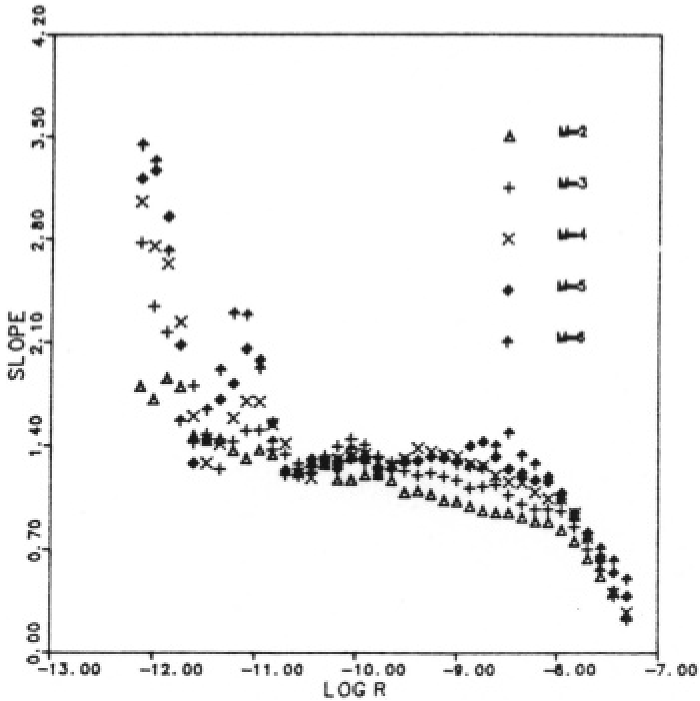
(a)

(b)

Figure 5.11 The GP Plot of C(R) vs. R for LD detrended monetary indexes. (a) SSM2. (b) DDM2.



(a)



(b)

Figure 5.12 The GP Plot of slope vs. R for LD detrended monetary indexes. (a) SSM2. (b) DDM2.

regions of intermediate R, which reflect the fractal structure of the attractors, is shown in Figure 5.11a and Figure 5.12a. The correlation dimension can be determined from the up-bond slope of the plateau region in Figure 5.11b and Figure 5.12b. The level of uniform noise in the data can be estimated from the left end of the plateau when R is small.

We calculated the correlation dimension with the time lag T varying from four to 38 (the decorrelation time of DDM2m). The pattern is not sensitive to changing T. The first zero-autocorrelation time is not the best choice for T in our cases, because a large T may cause folding in the phase space.

We found that the correlation dimensions of the investigated five monetary aggregates were between 1.3 and 1.5. They include four Divisia monetary index and one official simple-sum monetary indexes. For other monetary aggregates, no correlation dimension could be determined.

5.5 A continuous-time model of growth cycles with delayed feedback and bounded expectations

Given the evidence just presented, and given our comments on the desirability of a continuous-time model, let us consider a continuous-time representation of economic data with low-dimensional chaos.

The observed low correlation dimension and long decorrelation-time set constraint on the modeling of growth cycles. For a typical discrete model, T_d is approximately the same order of the time unit. The decorrelation time T_d for monetary attractors is more than 60 weeks. A continuous-time model would seem to be appropriate to describe monetary growth cycles. The minimum number of degrees of freedom required for chaotic behavior in autonomous differential equations is three. The low dimensionality of monetary attractors leads to the assumption that the monetary deviations are separable from other macroeconomic movements. The background of growth cycles can be approximately represented by a constant exponential growth trend, or the so-called natural growth rate.

After comparing the correlation dimension and the phase portraits of the data and alternative models, a delay-differential equation suggests itself as a good candidate. For simplicity, we consider only one variable here.

5.5.1 Deviations from trend and time delay in feedback

The apparent monetary strange attractors are mainly found in log-linear detrended data. This is an important finding to study control behavior in monetary policy. I assume that the general trends of economic development are perceived by people in economic activities as a common psychological reference or as the anchor in observing and reacting (Tversky and Kahneman 1974). Administrative activities are basically reactions to deviations from the trend. Accordingly I chose the deviation from the "natural growth rate" as the main variable in the dynamic model of monetary growth in the following equations:

$$\frac{dX(t)}{dt} = aX(t) + F[X(t-\tau)] \tag{5.1}$$

$$F(X) = X\,G(X) \tag{5.2}$$

where X is the deviation from the trend, τ is the time delay, a is the expansion speed, F is the feedback function, and G is the control function.

There are two competing mechanisms in the growth system. The first is the immediate response to market demand. It is described by the first term on the right of equation (5.1). The second term represents the endogenous system control described by the feedback function F. This consists of feedback signal X(t – τ) and control function G. The time delay τ exists in the feedback loop because of information and regulation lags.

There are several considerations in specifying F and G. We argue that the monetary policy follows simple rules based on the bounded rationality of monetary movements. We assume the feedback function F(X) has two extrema at X_m for the control-target floor and ceiling as argued by Solomon (1981). In order to describe the overshooting in economic management and the symmetry in growth cycles, G(X) should be nonlinear and symmetric, G (–X) = G(X). A simple exponential function describes the assumed nonlinear control function with flexible floor and ceiling or soft boundaries. Its control behavior is similar to that driving in a freeway with lower and upper speed limits.

$$G(X) = -b\exp\left(-\frac{X^2}{\sigma^2}\right) \tag{5.3}$$

where b is the control parameter, minus sign of b is associated with negative feedback, is the scaling parameter, and the extremes of F(X) are located at $X_m = \sigma/2$. Substituting equation (5.3) into equation (5.1) and (5.2) gives the following delay-differential equation, which can be called the soft-bouncing oscillator (SBO):

$$\frac{dX(T)}{dt} = \mathrm{a\,X(t) - b\,X(t-\tau)\,exp}\left(-\frac{\mathrm{X(t-\tau)}^2}{\sigma^2}\right) \tag{5.4}$$

We may change the scale by X = X′σ and t = t′τ, then drop the prime for convenience:

$$\frac{dX(t)}{dt} = a\tau X(t) - b\tau X(t-1)\,e^{-X(t-1)^2} \tag{5.5}$$

5.5.2 What can we learn from the model

No empirical phenomenon can be understood without theoretical reasoning. Empirical tests only offer some supportive arguments for theoretical judgment. The choice of chaotic model over stochastic model largely depends on if we can learn more information based on the same set of empirical data. Our answer is yes. The mechanism of intrinsic instability and the pattern of irregularity illustrated in nonlinear chaotic models are entirely foreign to linear stochastic models.

5.5.2.1 Phase transition and pattern stability

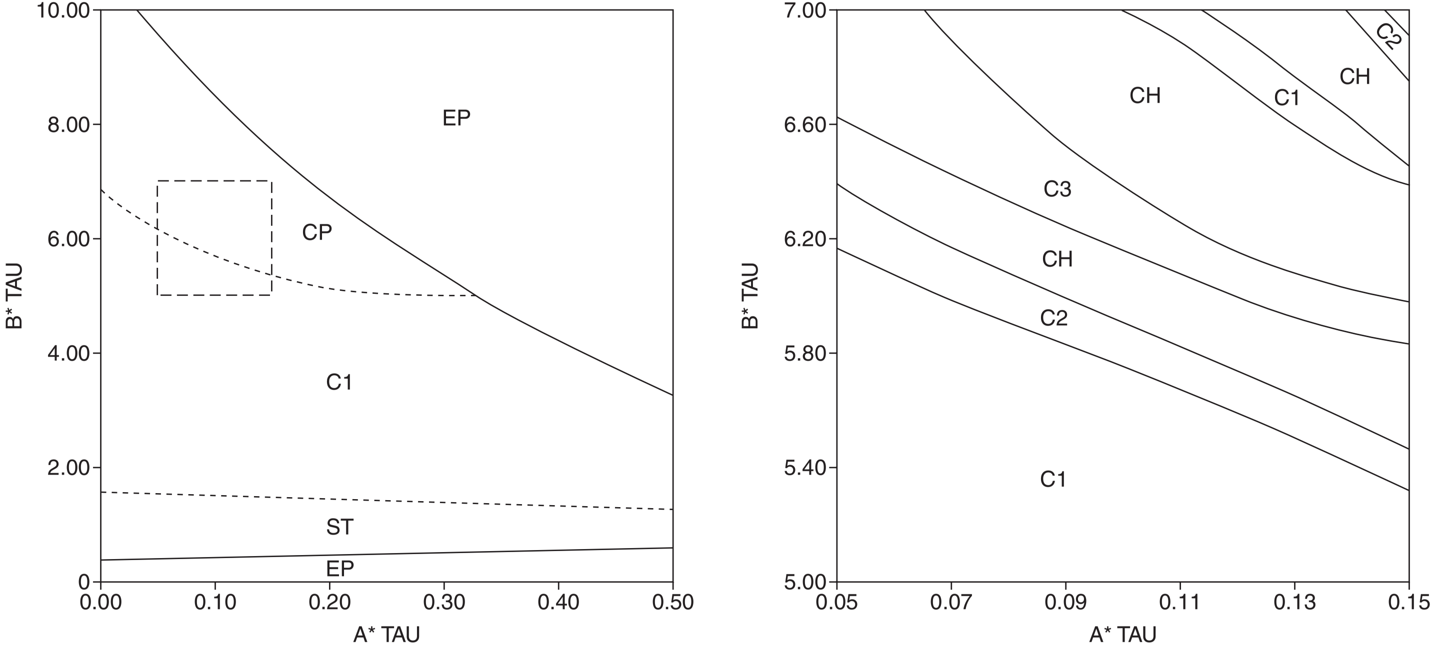
Figure 5.13a and 5.13b display qualitatively the phase diagram of equation (5.5) or SBO in the parameter space. The broad diversity of dynamic behavior includes steady state ST, limit cycle or periodic motion C1, and the explosive solution EP. The complex regime CP includes multi-periodic (C1, C2, C3) and chaotic regime CH. When parameter values change within each region, the dynamic behavior has pattern stability or phase stability, because the dynamic mode occupies a finite area in the parameter space. The phase transition occurs when parameters cross the boundary between different phases. It is observable when the wave pattern changes. Nonlinear dynamic models can explain both phase stability and phase transition. This property is not true for linear dynamical models such as the unit root model, since the unit-root is only marginally stable without phase stability.

5.5.2.2 Long wave and short cycles

In addition to seasonal changes, several types of business cycles have been identified by economists: the Kitchin cycles (three to five years), the Juglar cycles (7–11 years), the Kuznets cycles (15–25 years), and Kondratieff cycles (45–60 years) (Van Duijn 1983). Schumpeter suggested that these cycles were linked. Each longer wave may consist of two or three shorter cycles. This picture can be described by the periodic phase C2 or C3 in the CP regime of our model. The irregularity in long waves can also be explained by the chaotic regime CH. Our model gives a variety of possibilities of periodicity, multi-periodicity, and irregularity in economic history, although our data only show the chaotic pattern in monetary movements.

It is widely assumed that the long waves are caused by long lags, a belief coming from linear thinking (Rostow 1980). This condition is not necessary in our model, because the dynamic behavior of equation (5.5) depends on the product of $a\tau$ and $b\tau$. A strong overshooting with a short time delay has the same effect as a weak control with a long time delay, a similar point also made by Sterman (1985).

This model is so simple and general, and it could have applications beyond the monetary system in the market economy we discussed here. For example,



(a) (b)

Figure 5.13 The phase diagram of soft-bouncing oscillator (SBO) in parameter space. (a) Full scale. (b) The enlarged block area in (a) with alternative solution regimes.

the growth cycles and long waves caused by overshooting and time delay may also happen in centrally planned economies.

5.5.2.3 Simulating empirical cycles and testing numerical algorithms

In comparing model-generated patterns with empirical data, we may confine our experiments to certain regions of the parameter space. For example, we can estimate the average period T from four times the decorrelation time T_d. The time delay in monetary control due to regulation lag and information lag is between 20 and 56 weeks (Gordon 1978). If we estimate the time delay to be 39 weeks, we can simulate SSM2 LL time series by the solution by setting $\tau = 39$, $a = 0.00256$, $b = 0.154$, and $\sigma = 0.0125$. The model results match well the average amplitude A_m, decorrelation time T_d, positive maximum Lyapunov exponent λ, and correlation dimension D of the empirical time series.

We tested the theoretical models with power spectra and autocorrelation analysis. The approximated period T of the chaotic solution can be estimated from T_d measured by three to five cycles. It is close to the fundamental period T_1 ($= f_{1-}{}^{1}$). The fundamental frequency can be determined by power spectra. The error can be less than 3 percent when observation period covers 100 cycles. For SSM2 LL time series, the difference of T_d measured between 10 and 15 years is less than 5 percent. We can obtain valuable information about the fundamental period T_1 without knowing the exact parameters of the deterministic model.

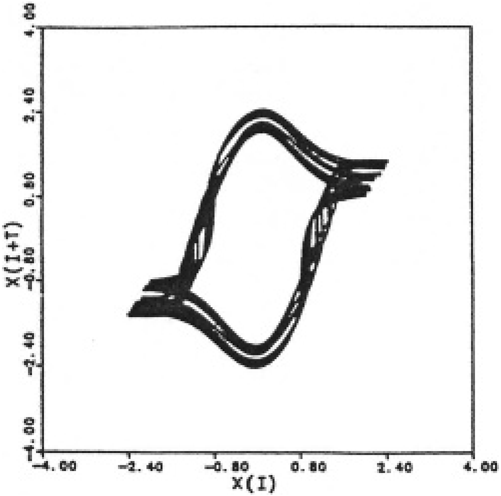
The small data sets cause the estimation of the correlation dimension to be biased downward (Ramsey and Yuan 1989). In our theoretical simulation of monetary cycles, the numerical result of the correlation dimension is 1.7 calculated with 1000 data points and 2.08 with 16,384 points for the same SBO model. The error is 18 percent in dimension estimation of the growth-cycle model. The results of monthly monetary data are still within the margin of numerical reliability because of their low dimensionality (Chen 1988b). Certainly, the numerical estimation of the correlation dimension for monetary indexes is only suggestive since the amount of data is small. Further empirical observations are needed to provide better evidence of monetary chaos.

The phase portrait and maximum map of theoretical model of monetary chaos are demonstrated in Figure 5.14. The theoretical monetary strange attractor rotates clockwise (Figure 5.14a), which mimics the movement of the monetary growth cycle in Figure 5.9a. The maximum map shows the qualitative picture of discrete-time chaos typically created by the Poincáre section (Figure 5.14b).

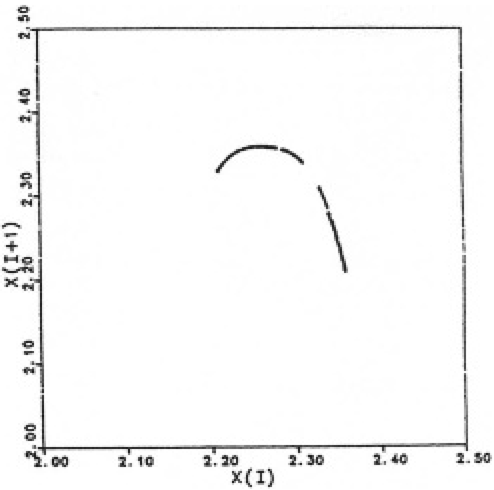
A brief summary of both empirical and simulating results is given in Table 5.1. The time unit of weekly data is converted to monthly for comparison.

5.5.2.4 Implications for forecasting and control policy

The predictive power of a chaotic economic time path is limited by the magnitude of the maximum Lyapunov exponent. Nevertheless, we may potentially recover more information from chaotic motion than from randomly generated movements.



(a)



(b)

Figure 5.14 The two-dimensional phase portrait of the chaotic solution of SBO. (a) Chaotic solution. (b) The maximum map.

We know that a long-term prediction of the chaotic orbit is impossible from the view of nonlinear dynamics. A medium-term prediction of approximate period T can still be made, if we identify strange attractors from the time series.

Let us discuss the meaning of the control parameters in equation (5.5) or SBO model. When $b = 0$, the monetary deviation from the natural rate will grow at a speed e^{at}. We define a characteristic doubling time t_a which measures the time needed to double the autonomous monetary expansion X(t) without control.

Table 5.1 Empirical indicators of monetary chaos

Name	*N (obs)*	*λ (/m)*	λ^{-1} *(m)*	T_d *(m)*	*D*
SSM2m	195	0.0242/m	41.3m	14m	1.3
DDM2m	195	0.0489/m	20.4m	38m	1.3
DDM3m	195	0.0218/m	45.9m	37m	1.3
DDLm	192	0.0397/m	25.2m	35m	1.3
SSM2w	807	0.0581/m	17.2m	14.2m	1.5
DDM2w	807	0.0791/m	12.6m	34.9m	1.4
DDM3w	807	0.0774/m	12.9m	34.2m	1.5
DDLw	798	0.0525/m	19.1m	32.3m	1.5
DSM2w	798	0.0585/m	17.1m	32.6m	1.3
SSM2t	1000w (16,384)	0.0688/m	14.5m	14.2m	1.7 (2.08)

Notes
λ is the largest Lyapunov exponent; Td is decorrelation time; D is correlation dimension. The time units are: one year = 12 months = 52 weeks, and one month = 4.3 weeks. SSM2t is the simulating time series generated by the theoretical monetary growth model and its correlation dimension n is calculated with 1000 and 16,384 data points respectively (Chen 1988b). Time series include simple-sum monetary aggregate index SSM2 and Divisia monetary index DDM2, DDM3, and DDL. Data source is Fayyad (1986). Empirical monetary indexes are LL detrended series.

Similarly, we can define a characteristic half time t_b, which measures the time needed to reduce the money supply to half its level, when a = 0 and X(t – τ) reaches the control target

$$X_m = \frac{\sigma}{\sqrt{2}} = 1.4 \text{ percent per year.}$$

The same is true for the contraction movements, since the feedback function G(X) is symmetric. Here t_a is 5.2 years and t_b is 7.4 weeks for SSM2 in our simulation. We see that even modest time delay and overshooting may generate cycles and chaos.

For policy considerations, the phase diagram of the model suggests that the steady state in money supply can be achieved by carefully adjusting the control parameter b or the time delay τ (see Figure 5.13). For example, we can fix a (= 0.1) and τ(= 39 weeks) and set b in stable regime (0.41 < b < 1.51 or 29.5 weeks < t_b < 108.7 weeks); we may also fix a (= 0.1) and b (= 6.0) but choose τ in ST regime (14.4 minutes < τ < 1.3 days). Obviously, reducing overshooting is much easier than cutting time delay in monetary control. These figures give a qualitative picture of monetary target policy (Chen 1988b).

5.5.3 Linear approximations of nonlinear model

Let us study the relationship between the nonlinear dynamic model (5.4) and its linear approximations under some simplifying conditions. Difference equation can be obtained as an approximation of nonlinear difference-differential equation (5.4) when the time unit is chosen to be the time delay τ ($\tau = 1$) and X(t) is much less than the control target σ, and b is less than σ^2, we have

$$\frac{dX(t)}{dt} = X(n+1) - X(n)$$

$$= a\,X(n) - bX(n-1)\,e^{-\frac{X(n-1)^2}{\sigma^2}}$$

$$= aX(n) - b\,X(n-1) - b\frac{X(n-1)^3}{\sigma^2} \tag{5.6}$$

or

$$X(n+1) = c_1X(n) + c_2X(n-1) + \omega X(n-1)^3 \tag{5.7}$$

where

$$c_1 = (1+a),\; c_2 = -b,\; \omega = \frac{b}{\sigma^2}.$$

Equation (5.7) looks like an AR(2) process when the nonlinear term $\omega X(n-1)^3$ is ignored and replaced by some noisy residual term. Although AR(2) approximation may be very useful and convenient in econometric analysis, its drawbacks and limitations are also significant. First, the sampling time unit should be the time delay that is between 20 and 56 weeks, equivalent to quarterly or annual data (Gordon 1978). Second, AR(2) model is misleading in its stochastic nature, because the residual is generated by the nonlinear term with long-term correlations, not random noise with short correlations.

We may also have a differential version of equation (5.6) when the time delay is ignored.

$$\frac{dX(t)}{dt} = -aX(t)\left[ge^{-\frac{X(t)^2}{\sigma^2}} - 1\right]$$

where

$$g = \frac{b}{a} >> 1,$$

so the equation has a fixed point solution.

Friedman believes that the natural rate in economies can be achieved in so-called long-run equilibrium (Friedman 1969). In our case, constant growth rate can be realized when the time delay in control process is zero. Obviously, this is an idealistic case but unrealistic situation. The concept of long-run equilibrium in static analysis can be considered as the fixed point solution in nonlinear dynamic systems. Although steady state is hard to achieve due to time delay and over-reaction in human behavior, equilibrium or steady state can still serve a reference regime for control target.

This example demonstrates the connection between nonlinear economic dynamics and linear dynamics. Static equilibrium analysis could be considered as the first approximation in the generalized framework of disequilibrium dynamics.

5.6 Brief summary and future directions

So far we have only few evidence of economic chaos from empirical data. However, theoretical powers of modeling complex behavior and mathematical generality of nonlinearity strongly support the promising development of chaotic economic dynamics. The prerequisite for this advancement is its tremendous demand of empirical information and computational power to handle nonlinear problems.

The question is how to extend our scope of economic analysis and advance our study of economic chaos. Four directions should be explored in the near future.

- Re-thinking the operational framework of chaos theory for empirical studies

Standard definition of deterministic chaos is based on the positive Lyapunov exponent. Fractal dimension is also important in characterizing strange attractor (Hao 1990). These criteria are useful in studies of theoretical models and computer experiments, but very restricted in empirical analysis. We should develop operational guidelines to choosing chaotic or stochastic approach in empirical analysis.

Prigogine pointed out that deterministic chaos is only a partial feature of complex systems. Long-range correlation is the fundamental character of complex dynamics (Nicolis and Prigogine 1989). This definition of chaotic process may help econometricians in understanding chaos and noise, since econometric analysis is based on stochastic process with short correlations.

In my experience of analyzing large number of economic time series, taintless cases of economic chaos are rare, but long-term correlations appeared in empirical data are abundant. The real problem is always more complicated than theoretical models. It is true both for natural sciences as well as social sciences. For example, discovering the beautiful structure of hydrogen spectra is a rare case even in physics. However, it is discontinuity of frequency distribution widely observed in optical spectra strongly support the quantum theory.

No empirical observation can be done without theoretical reasoning, and no matter it works in an explicit or implicit way. The difference lies deeply in theoretic foundation. Some econometricians use whitening technique such as multiple differencing to eliminate correlations and justify stochastic models. We try long-term detrending methods to extract correlation signal and recover deterministic mechanism.

- Re-examining the theoretical foundation of econometrics

Economists often compare economy with weather (Goodwin 1990). Although the irregularities of their behavior are very similar, their theoretical perspectives are just opposite. The failure of econometric forecasting based on stochastic approach (Dominguez *et al.* 1988; Wallis 1989) and the success of weather forecasting based on deterministic approach (Tribbia and Anthes 1987) dramatizes the difference of their methodological foundation.

- Expanding the empirical base of economic studies

Genuine economic dynamics cannot be discovered by curve fitting in terms of statistical techniques. Current controversy of chaos versus noise cannot be completely settled by numerical tests based on limited contaminated data.

Consider the problem of weather forecasting. The irregular time paths of temperature, rainfall, and other observations are easily seen in short-time observations. Linear stochastic models may fit the data and give good explanation of the short history. However, cumulative observations reveal regularity in recurrent pattern. Although data mining in weather forecasting can be established from empirical data, theoretical understanding went a long way through fluid dynamics and state equation in thermodynamics.

The improvement of weather forecasting has been achieved by expanding the data base through global weather-station network and satellite-surveillance techniques. Increasing computer power also facilitates increasing precision of nonlinear models and weather forecasting. However, current resource constraint in empirical economic research force the economic profession basically confined in thought experiments and linear models because of lacking empirical data and computing power in the information age. Long-term investment in "economic weather station network" and research efforts in complex economic dynamics is essential for advancing empirical economic science.

Exploring economic chaos opens a new way to understand human behavior and social evolution. The interdisciplinary character in developing evolutionary dynamics and nonlinear economics has not only changed the ways we think, but also the institution in which we organize economic research.

Acknowledgments

The author is grateful to Professor I. Prigogine for his continuous support, Professor W.A. Barnett for providing monthly monetary data, and Professor R. Day for his careful reading my manuscript and valuable suggestions. He also thanks T. Stangos and C. Sayers for bringing the problems of the unit-root hypotheses, and the data processing effect to the attention of the author. The stimulating comments from W.A. Brock, E. Mosekilde, R.M. Goodwin, C.W.J. Granger, J.B. Ramsey, J. Conlisk, and anonymous referees are greatly appreciated. I have incorporated with permission of the publishers (MIT Press) a considerable amount of material from Chen (1988b). Finally, I greatly appreciate the help from Dr. D. Kaplan for applying direct test to economic data.

Appendix A: a direct test for determinism in monetary time series

A new algorithm of direct testing determinism has been developed by Kaplan and Glass (1992). It turns out to be a useful tool to distinguish between determinism and randomness. Their idea is simple.

At each state in the state space, a deterministic dynamic flow has only one direction because of its deterministic rule, while a stochastic system has more than one possible value. By calculating local coarse-grained flow averages and statistics, one may have a better chance of dealing with noisy and short time series than calculating Lyapunov exponents and correlation dimensions.

We sent two time series of 807 points in length, DLSM2 and PCSM2, to Kaplan. PCSM2 is a simulated time series generated by SBO simplified equation (5.5). DLSM2 is the log-linear detrended SSM2 LL weekly time series in Figure 15.9a. Kaplan finds clear conclusions for both time series. We now provide further evidence of deterministic monetary chaos courtesy of Kaplan (private communication, April 9, 1992).

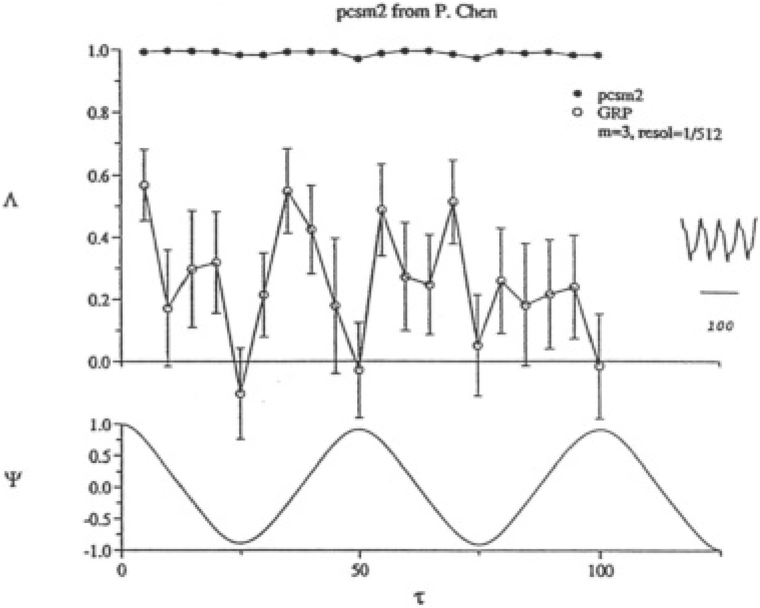
PCSM2 easily passes the test of determinism as shown in Figure 5.15a: the Lambda-bar is close to 1 for the deterministic signal, and the contrasting Gaussian random process with the same autocorrelation function is much less and near zero, as is expected from theory.

DLSM2 in Figure 5.15b shows that the signal is more deterministic than a Gaussian random noise. Its low resolution is due to short time series and high level of noise. It would be helpful for economic studies to have a longer time series of empirical data in the future.

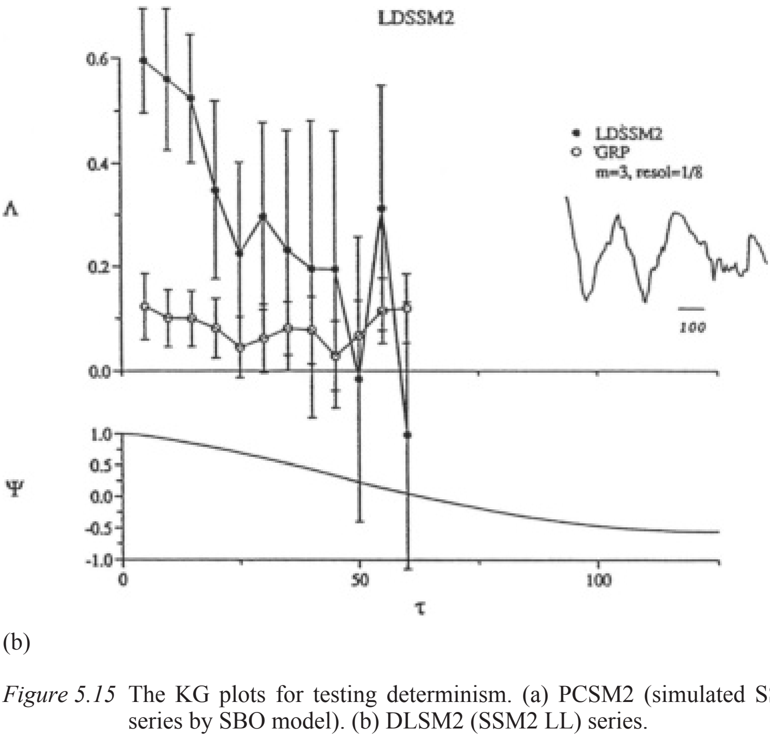
Appendix B: testing correlation resonances in searching for chaos

Prigogine pointed out that complex spectral theory plays a critical role in dealing with unstable dynamic systems (Prigogine 1993). Of special importance is the concept of correlation resonances (Ruelle 1986), which are the peaks of correlation spectra of time series data. We call this approach “the complex spectral analysis of correlations (CSAC).”

A complex Fourier spectrum is a natural generalization of conventional Fourier spectrum when unstable states are present. The complex spectral representation in physics is originated from the problem of decaying states and resonances in quantum mechanics (Gel’fand and Vilenkin 1964). The CSAC shifts interest from the original time series to the correlation functions. Resonances in



(a)



(b)

Figure 5.15 The KG plots for testing determinism. (a) PCSM2 (simulated SSM2 time series by SBO model). (b) DLSM2 (SSM2 LL) series.

Table 5.2 Testing economic chaos with six time series

Name	*S&PFD*	*S&P*	*M2*	*GNP*	*Brent*	*WTI*
N-points	1499	1500	807	164	580	580
Period	1952–1981	1952–1981	1969–1984	1946–1988	1983–1985	1983–1985
Time unit (Δ)	5 days	5 days	week	quarter	day	day
T_d (Δ)	2	136	61	22	44	44
λ (Δ^{-1})	0.014	0.0145	0.013	0.032	0.020	0.018
λ^{-1} (Δ)	71.4	69	74.1	31	50	56
D	no	2.0	1.5	2.5(?)	1.5	2.2
P-Portrait	random	spiral	spiral	spiral	spiral	spiral
KG Test	no	no	yes	?	no	no
T_1	no	43.8 years [?]	4.39 years	33.4 years	140.9 days	110.5 days
τ_1		43.9 years [?]	2.44 years	*	55.7 days	74.4 days
T_2	no	3.33 years	1.98 years	12.5 years	24.2 days	21.3 days
τ_2		13.0 years	0.91 years	?	47.7 days	*
T_3	no	1.09 years		5.6 years	18.5 days	
τ_3		*		?	20.6 days	
chaos evidence	no	weak	strong	some	weak	weak

Notes

Here λ is Lyapunov exponent, T_d the decorrelation time measured from the first zero of autocorrelations, and D the correlation dimension. P-Portrait represents phase portrait. KG stands for Kapland-Glass direct test.

$$T\left(=\frac{2\pi}{\omega}\right)$$

is the period of correlation resonance,

$$\tau\left(=\frac{1}{\alpha}\right)$$

is the lifetime of unstable mode based on CSAC algorithm. Time series include S&D (Standard & Poor's 500 index) with FD and LL series, monetary index M2, real GDP, Oil price indexes include Brent and WTI (West Texas Intermediate). Data sources are Federal Reserve in St. Louis.

The question mark (?) casts doubt to the numerical reliability when data is short. The asterisk (*) indicates that the extremely slow decay actually means persistent oscillation within the numerical precision.

Henon map were studied by Isola (1988). The complex spectral theory for non-integrable large Poincáre system developed by Petrosky and Prigogine (1991) has been applied to studies of highly chaotic maps by Hasegawa and Saphir (1992). These developments form the foundation for empirical applications of CSAC approach.

Zhang, Wen, and Chen (1992), have improved the CSAC numerical technique for empirical test with limited data points. The procedure is first to calculate autocorrelations of the time series data, then calculate the power spectra and locate complex singularities of correlations by means of the Pade rational function approximation, and finally, estimate resonance frequencies and their exponential decay rates.

We tested several log-linear detrended data, including S&P 500, Federal Reserve M2, crude oil prices including Brent oil index and WTI index, and real GNP data. Our initial results reported in Table 5.2, which provided strong evidence of economic chaos in monetary data, weak evidence in stock market and oil price data, some skeptical evidence in the case of GNP.

The CSAC approach is a new test added to the package of numerical tests briefly outlined in this chapter. Each test may reveal one or two aspects of nonlinearity and long-range correlation. The tests are complementary and should all be used in a weighted judgment.

The empirical findings shed important light on endogenous dynamics. First, the generalized concept of unstable periodic modes breaks the intellectual barrier between chaos and noise – the two idealized models of complex reality. Now we may define the peaks (resonances in correlation power spectra) with exponential decays as one of many operational indicators of typical chaos.

Second, the existence of correlation resonances builds a link between non-equilibrium evolutionary processes and static equilibrium representations. The correlation resonances reveal the co-existences of various characteristic fluctuations. The lifetime of metastable modes provides the quantitative measure of the transition from disequilibrium to equilibrium.

The results of the observed resonance frequencies are consistent with common experience of business cycles (Gordon 1986). The different rates of exponential decay provide good indicators of adjustment speed for persistent medium business cycles and faster dissipative innovation shocks.

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,…, $d^nX(t)/dt^n$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), ΔX(t),…, A^mX(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

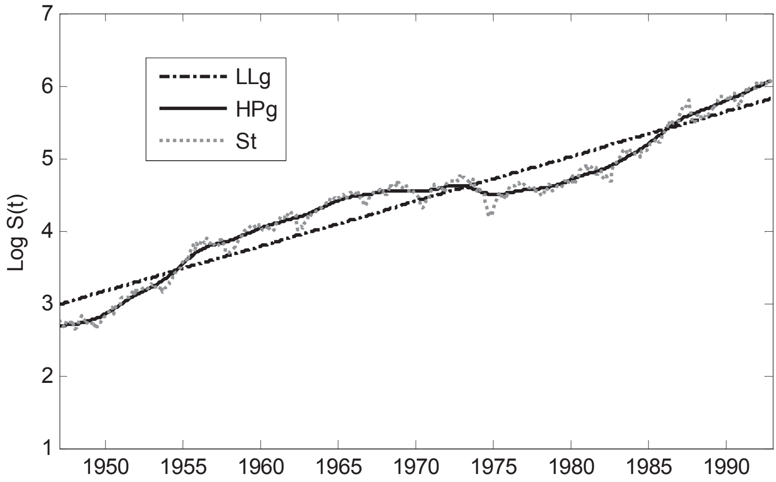
Detrending	*Mean*	*STD*	*Variance*	T_d *(month)*	P_{dc} *(year)*
FD	0.012	0.1123	0.0126	1.94	0.7
HP	0.008	0.2686	0.0722	8.93	3.0
LL	0.427	0.3265	0.1066	85.6	28.5

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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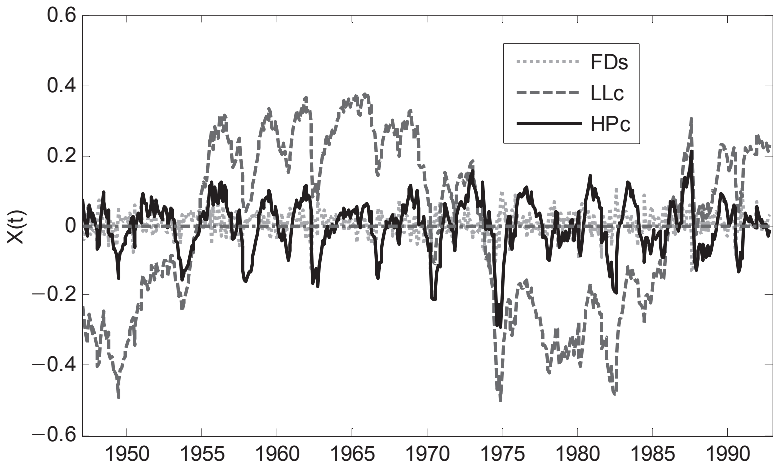

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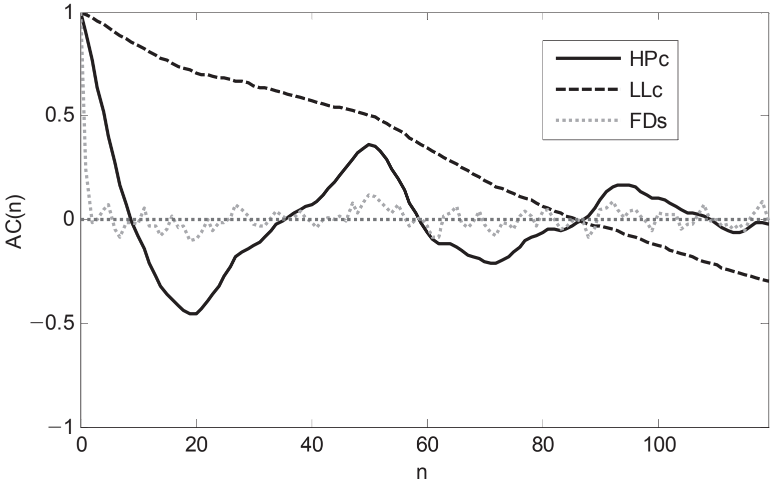
Figure 6.1 Fluctuation patterns from competing trend–cycle decompositions, including FD, HP, and LL (log-linear) detrending, for the logarithmic FSPCOM monthly series (1947–1992). (a) HPg and LLg growth trend. St is original series. (b) HPc, LLc, and FDs cyclic series. (c) Autocorrelations of HPc, LLc, 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 $X_0(t)$ 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

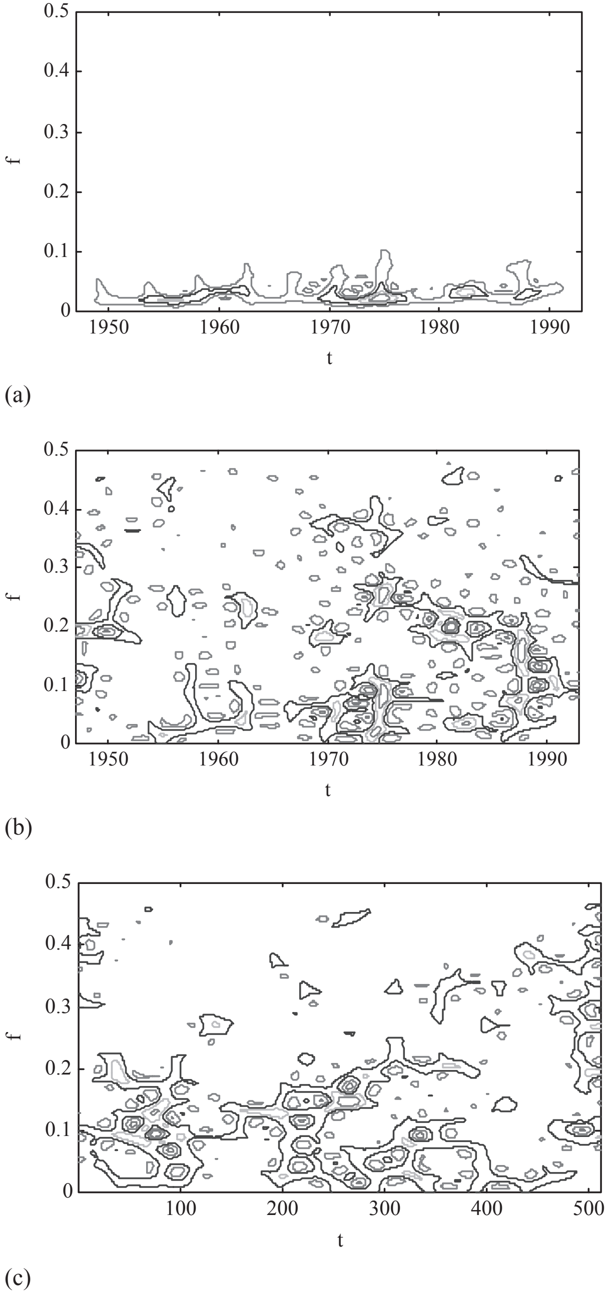


Figure 6.2 Time–frequency representation of empirical and simulated series from FSPCOM logarithmic detrended data. (a) HP cycles. (b) FD series. (c) AR(2) model of FD series.

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.

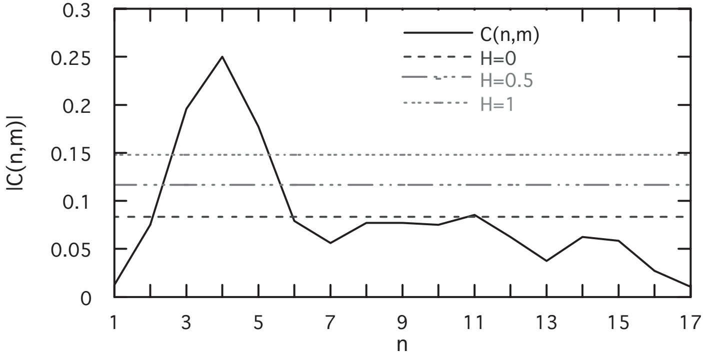
The shape of the mask function is determined by the intensity of Gabor components. We should point out that a conventional test, such as the Durbin-Watson residual test, may not be applicable here, because residuals may be color noise. Our main target is catching the main deterministic pattern in the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



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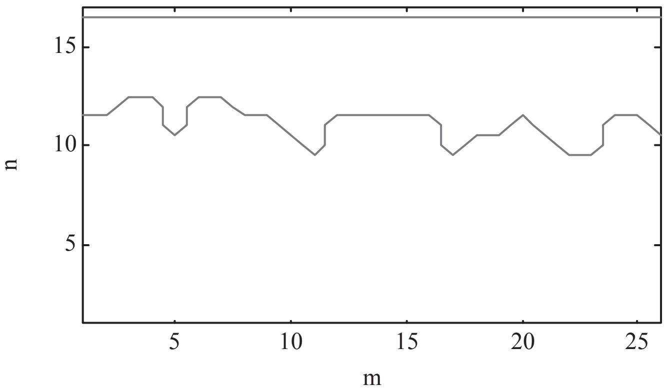

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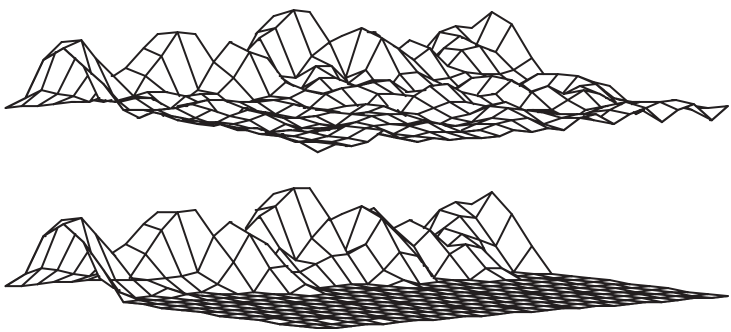


(c)

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.

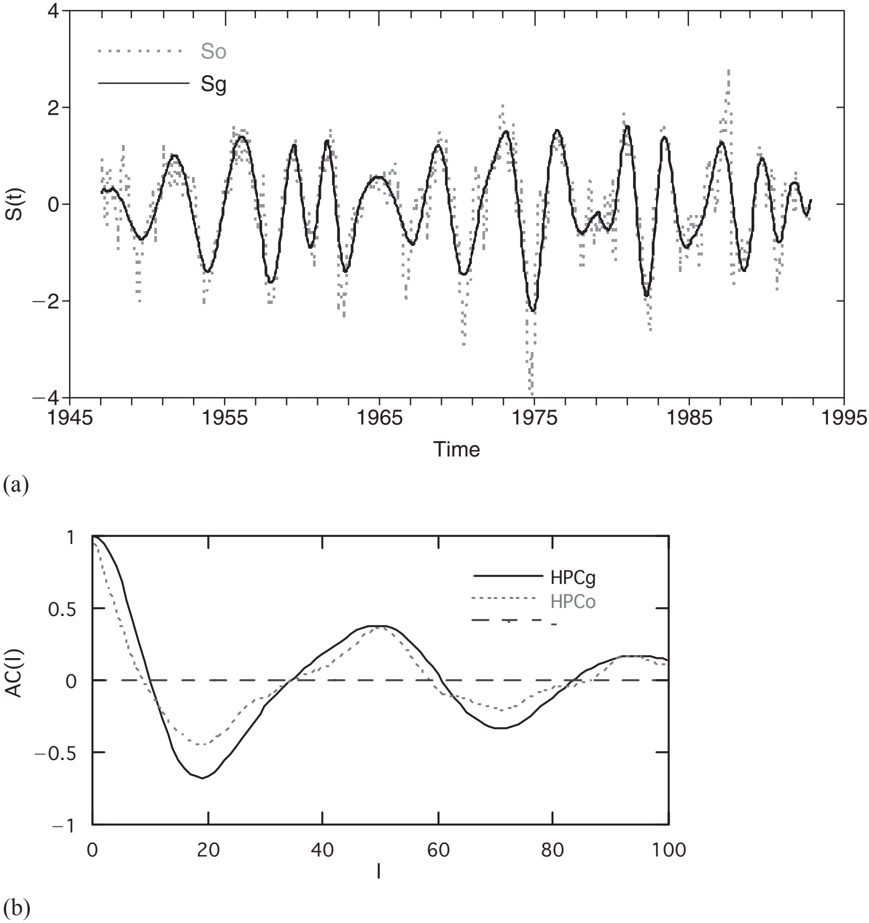


Figure 6.4 The original and reconstructed time series of HP cycles. (a) The original and filtered HP cycles (H = 0.5). (b) Autocorrelations of the original and reconstructed series.

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.

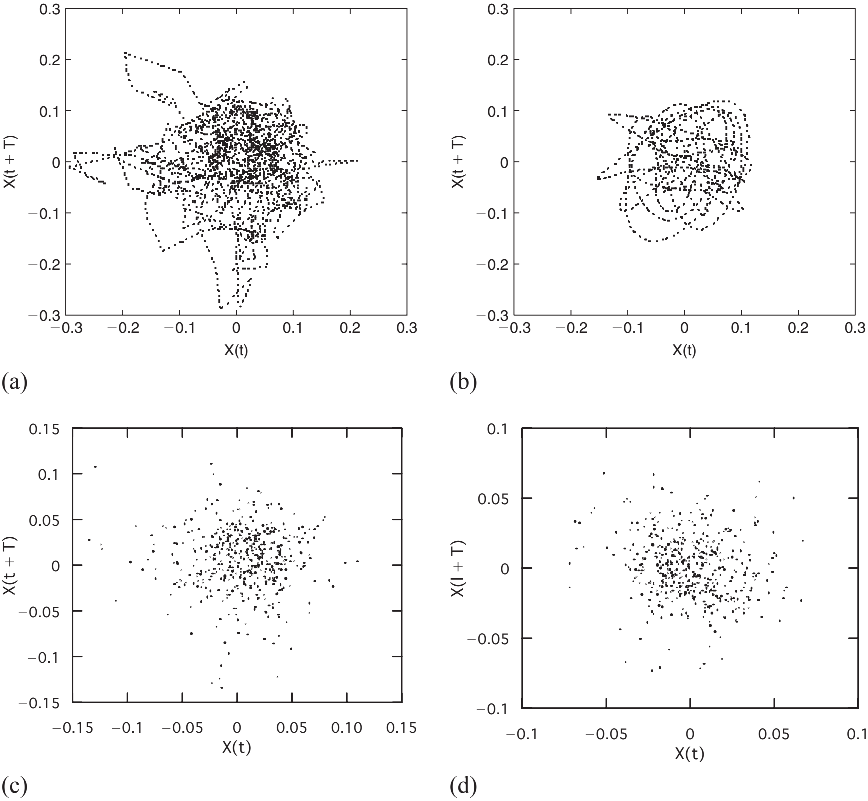


Figure 6.5 Patterns of phase portraits for FSPCOM series. (a) HPc unfiltered series. (b) HPc filtered series. (c) FD series. (d) Filtered AR(2) series.

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.

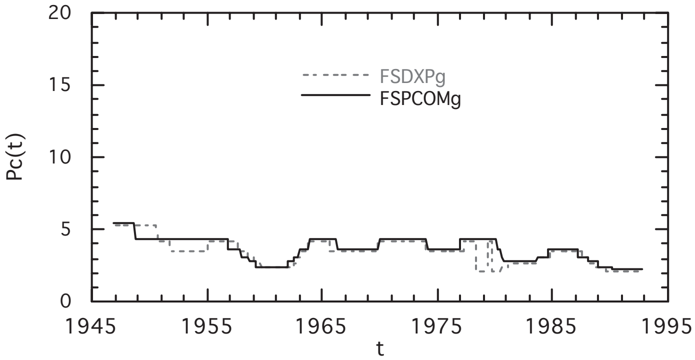
From Table 6.3, we can see that FSPCOM and FSDXP are quite similar in frequency pattern and dimensionality. The characteristic period P_c from the time–frequency analysis and the decorrelation period P_{dc} from the correlation analysis are remarkably close. It is known that a long correlation is an 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).

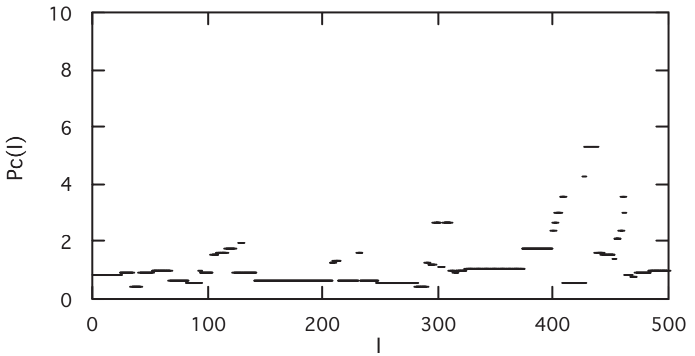
The extraordinary resilience of the stock market can be revealed from the stable frequency pattern under the oil price shocks in 1973, 1979, and the stock market crash in October 1987. These events generated only minor changes in the characteristic period P_c for FSPCOM and FSDXP indexes.

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.



(a)



(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)

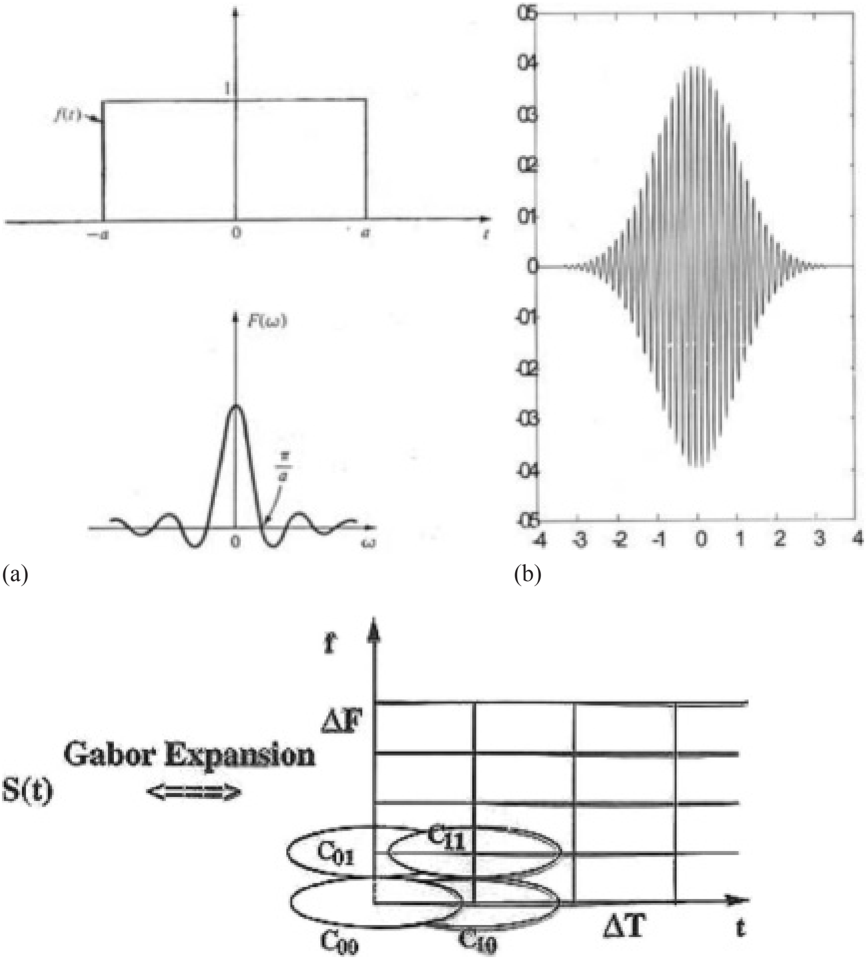


Figure 6.7 Construction of the Gabor space based on the uncertainty principle in time and frequency. (a) The uncertainty principle in time and frequency. (b) The Gabor wavelet (coherent state in quantum mechanics). (c) The Gabor space in discrete time and frequency lattice space.

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.

7 Trends, shocks, persistent cycles in evolving economy

Business-cycle measurement in time–frequency representation[1]

> Analyzing business cycles means neither more nor less than analyzing the economic process of the capitalist era.
>
> Cycles are not, like tonsils, separable things that might be treated by themselves, but are, like the beat of the heart, of the essence of the organism that displays them.
>
> (Schumpeter 1939)

7.1 Introduction

An alternative title for econometric literature could be: "Business-cycle measurement without model specification."

One basic difficulty in business-cycle studies is that measurement is behind observation. We need analytical tools to characterize economic complexity. Hitherto, studies of business cycles are based on two alternative methods in time series analysis. Correlation analysis measures mean, variance, and correlations based on the covariance-stationary model of i.i.d. (the identical independent distribution) process in the time domain. The Fourier spectral analysis measures frequency and amplitude based on the cycle-stationary harmonic oscillations in the frequency domain. However, all these quantities are subject to changes in the time scale of business cycles. Real signals of economic movements contain both stochastic and deterministic components; therefore, we need new tools in time series analysis and business cycle modeling.

Economists realize the need to study nonlinearity and nonstationarity. There are two strategies to address the issue. One strategy is developing nonlinear and nonstationary versions of correlation analysis (Granger and Teräsvirta 1993). Another strategy is developing nonlinear and nonstationary representations of spectral analysis (Chen 1993a). We will focus on the second approach in this chapter, since it is still in its infancy.

To address time-dependent phenomena, we introduce a new tool of time–frequency analysis which originated in quantum mechanics and acoustic physics (Wigner 1932; Gabor 1946). A recent development in signal processing provides an efficient algorithm to calculate time–frequency distribution, which is a powerful tool to identify deterministic components from short and noisy signals (Qian and Chen 1993, 1994).

Most economic indicators have fluctuations around a growth trend. Different detrending methods lead to competing perspectives in business-cycle theory. Two detrending methods are tested by time–frequency analysis: the first differencing (FD) and the Hodrick–Prescott (HP) smoothing filter. We find HP is much better than FD in revealing deterministic patterns from economic time series (Chen 1996a).

From a wide range of aggregate data, we find the existence of persistent cycles, in addition to color noise. Spectral analysis not only provides complementary evidence of "co-movements" of business fluctuations (Lucas 1981; Kydland and Prescott 1990), but also reveals distinctive patterns of frequency evolution. It is found that characteristic frequencies of business indicators are remarkably stable. Only minor changes occurred under such events, for example, the oil price shocks in 1973 and the stock market crash in 1987. Surprisingly, more significant changes happened during the Vietnam War and the Reagan administration. The time lag between frequency responses of different indicators provides important information about the propagation mechanism in the real economy. A new approach of economic diagnostic and policy evaluation can be developed quantitatively.

The new perspective of time–frequency analysis indicates fundamental barriers for Friedman's rational arbitrageurs against market disequilibrium. The role of time scale, observation reference, dynamical instability, and information ambiguity in studies of business-cycle theory is discussed.

7.2 Time–frequency representation and complex economic dynamics

It is known that the deterministic and the stochastic approach are complementary representations of dynamical systems. There are trade-offs in finite realizations of empirical signals. Which representation is useful in science is not a matter of philosophical debate, but a subject of empirical experiment.

Recent development of nonlinear economic dynamics demonstrates that business fluctuations can be explained by deterministic chaos (Benhabib 1992; Day and Chen 1993). Standard tests of deterministic chaos are based on the phase space representation. The phase space approach has limited applications in empirical analysis, since a large number of data points and low level of noise is needed to calculate correlation dimension or construct the Poincáre section (Chen 1988a, 1993a). In contrast, time–frequency analysis has a much stronger power in dealing with noisy data.

Time–frequency analysis is a powerful tool in distinguishing white noise and complex cycles. Complex cycles are nonlinear chaotic cycles with irregular amplitudes and sophisticated frequency patterns, which are generalizations of linear harmonic cycles with regular amplitudes and well-defined frequencies.

7.2.1 Time–frequency distribution and the uncertainty principle

The simplest time–frequency distribution is the short-time Fourier transform (STFT hereafter) by imposing a shifting time window in the conventional Fourier spectrum. STFT has poor resolution in the frequency domain caused by the finite square window in the time domain.

The Wiener–Khinchine theorem indicates that the autocorrelation and the power spectrum are Fourier pairs for a continuous time stationary stochastic process (Priestley 1981). A natural generalization for the nonstationary process is introducing the instantaneous autocorrelation function $R_i(\tau)$ in the time-dependent power spectrum $P(t, \omega)$:

$$P(t,\omega) = \frac{1}{2\pi}\int R_t(\tau)\ \exp(-i\omega\tau)d$$

where the angular frequency $\omega = 2\pi f$.

Considering a symmetric time window, $R_i(\tau)$ can be replaced by the kernel function

$$s\left(t+\frac{\tau}{2}\right)s^*\left(t-\frac{\tau}{2}\right)$$

to produce a time-dependent power spectrum called the Wigner distribution (WD) (Wigner 1932):

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

An important development in time–frequency analysis is the Gabor expansion (Gabor 1946). The best resolution in the frequency domain can be achieved by imposing a Gaussian window according to the uncertainty principle in signal processing (Gabor 1946; Papoulis 1977):

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

where the equality holds only for the Gaussian envelope function of harmonic cycles.

Unfortunately, both the Wigner distribution and the Gabor expansion are un-orthogonal. The Wigner distribution is hard to calculate in continuous time because cross-interference terms are generated by non-orthogonal bases.

A synthesis of these two approaches (WGQ hereafter) leads to a good resolution and efficient algorithm (Qian 1993; Qian and Chen 1994). The Wigner distribution can be decomposed via the orthogonal-like Gabor expansion in discrete time and frequency. The localized symmetric base function has the form:

$$WD_b(t,\omega) = 2e^{-\left[\left(\frac{t}{\sigma}\right)^2 + (\omega\sigma)^2\right]}$$

The time–frequency distribution series are constructed as approximations of the Wigner distribution.

$$TFDS_D(t,\omega) = \sum_0^K P_d(t,\omega)$$

The zero-th order of time–frequency distribution series leads to STFT. The infinite order converges to the Wigner distribution. For applied analysis, second or third order is a good compromise in characterizing frequency representation without severe cross-term interference.

The WGQ representation in time–frequency analysis has important properties in physics and economics. The Wigner distribution ensures the conservation of energy density. This implies the conservation of variance in a time series analysis that is a key constraint in statistical analysis. The Gabor expansion catches periodic components under local observation. The time–frequency distribution series retain leading terms in the energy distribution. These features are critical in analyzing complex dynamics.

7.2.2 Time–frequency analysis of noise and chaos

The development of nonlinear dynamics provides an alternative model of seemingly erratic movements: deterministic chaos, including white chaos (such as the logistic map and Henon map) in discrete time and color chaos (such as Rössler model) in continuous time (Hao 1990). The "color" of continuous-time chaos is characterized by its characteristic frequency f_c or characteristic period P_c observed in spectral analysis.

There are some limitations for spectral analysis in testing deterministic chaos. To avoid aliasing effect, the normalized frequency window in spectral analysis is one half, or P_{min}, the lowest period observable, is two. The characteristic period and the characteristic frequency of white chaos are equal to one. Therefore, white chaos is outside the observational window. Spectral analysis alone is not sufficient to test the existence of color chaos; complementary measurements are needed (Chen 1993a). For studies of business cycles, the discovery of a characteristic frequency of erratic time series provides essential information about the components of deterministic cycles, regardless of whether they are pure color chaos or mixed color noise.

In testing deterministic chaos, the power spectrum plays an important role in studying color chaos in laboratory experiments (Swinney and Gollub 1978). In testing chaotic signals, thousands to hundreds of thousands of data points are required by the power spectrum. The noise level should be kept between 2 and 5 percent. The WGQ spectrogram has much stronger power to distinguish deterministic cycles from stochastic noise (Chen and Qian 1993; Chen 1996a).

The strong power of time–frequency analysis can be understood from the energy distribution of signals. White noise is evenly distributed in time–frequency space while deterministic cycles are highly localized. The noise level in the power spectrum is an integration of the energy distribution in the time domain; therefore, the time–frequency distribution has a much higher signal/noise ratio than that of the power spectrum. For example, the autoregressive (AR) model can produce artificial cycles in the power spectrum. It cannot generate a stable frequency line in time–frequency representation (Chen and Qian 1993).

Econometric analysis assumes that all economic variables are random variables. From the view of signal processing and pattern recognition, testing mixed signals of cycles and noise is a more realistic task. Our investigation will focus in this direction. Typical WGQ representations of noise and chaos are shown in Figure 7.1.

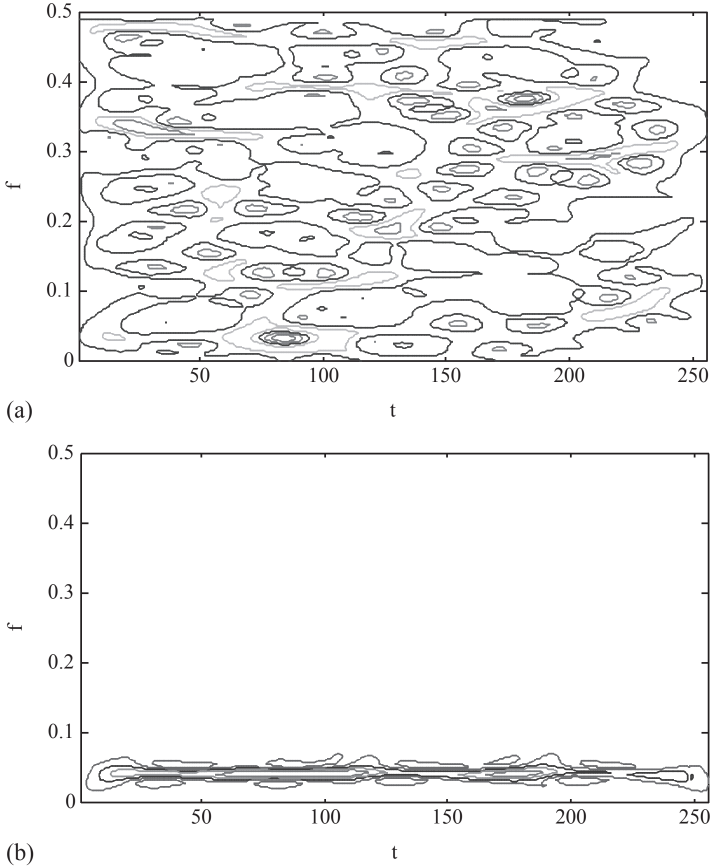
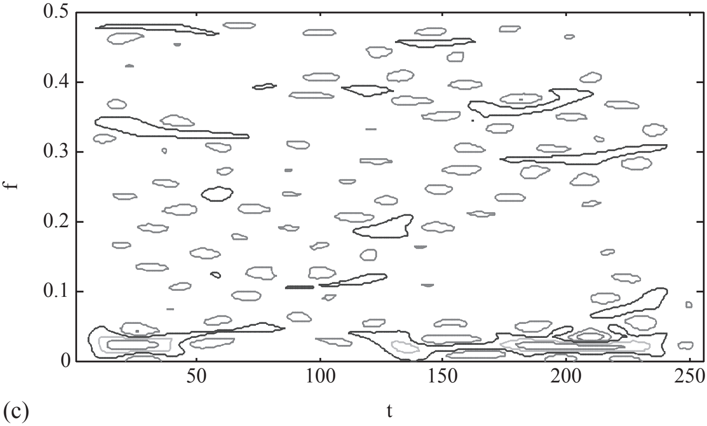
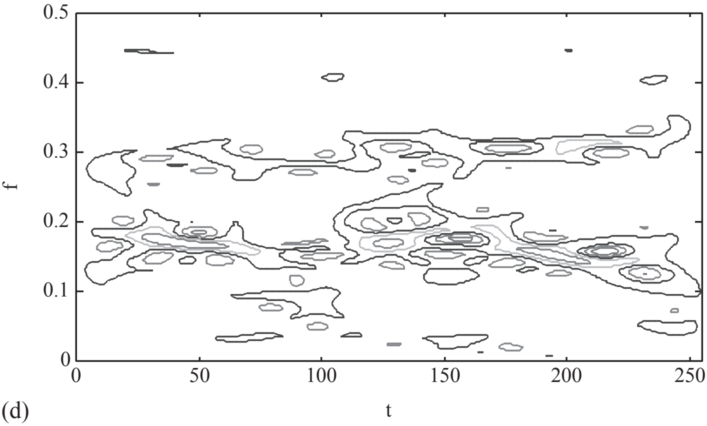


Figure 7.1 The WGQ spectrogram of noise and chaos (N = 256). (a) Gaussian white noise. No stable frequency line exists. (b) Rössler strange attractor is generated by three-dimensional differential equations $dX/dt = -Y - Z$, $dY/dt = X + 0.2Y$, $dZ/dt = 0.2 - 5.7Z + XZ$ (Rössler 1976). The time unit is adjusted to appear a business cycle frequency. *continued*



(c)



(d)

Figure 7.1 (c) Color noise modeled by Rössler chaos plus 200 percent noise (measured by the standard deviation). (d) Color chaos generated by the soft-bouncing oscillator with two time delays (Wen 1994). $dX/dt = 100\, X(t - 0.183) \exp[-200\, X(t - 0.183)^2] - 6X(t - 0.183) - Y(t - 0.048)$, $dY/dt = X(t)$.

Under WGQ representation, deterministic signals are characterized by a localized horizontal zone in the time–frequency space, while noise signals are featured by drop-like images distributed in wide time–frequency space. The patterns of color noise and color chaos are not easy to distinguish under numerical analysis, especially in the case of high-dimensional chaos (Wen *et al.* 1994; Wen 1993, 1994).

7.3 Trend–cycle decomposition and cycle identification

The detrending problem in business-cycle studies is closely related to the observation reference in economic theory. Many controversial issues in macroeconomic studies, such as the over-smoothness of consumption, the excess volatility of stock prices, and the debate of chaos versus noise in economic aggregates, are closely related to competing detrending methods (Hall 1978; Shiller 1989; Brock and Sayers 1988; Barnett and Chen 1988; Chen 1988a, 1993a).

Two most popular detrending methods are log-linear (LL) detrending and first differencing (FD) detrending. Their theoretical perspectives are called trend-stationary (TS) and difference-stationary (DS) time series in econometrics. The HP filter is a generalization of the LL detrending (Hodrick and Prescott 1997).

Econometric studies of detrending filters are based on a key assumption that economic time series can be characterized by linear stochastic processes (Nelson and Plosser 1982). The main analytical tools are correlation analysis and frequency analysis of stationary process (King and Rebelo 1993). The whole picture will be quite different, if testing signals are not generated by white noise, but by color noise. In testing the performance of FD and HP filters, we use simulated time series of color noise and a wide range of empirical data, including 16 economic aggregates.

7.3.1 Correlation cancellor (FD) and trend smoothing filter (HP)

The differencing procedure can be considered as a linear filter f(L) or F(L), with L as the lag operator.

$$Y(t) = X(t) - X(t-1) = f(L)\,X(t) = (1-L)\,X(t)$$

$$X(t) = F(L)\,Y(t) = (1-L)^{-1}\,Y(t)$$

The differencing is a non-invertible filter with marginal stability. Its main function in econometric modeling is a correlation cancellor. Actually, the differencing is not a whitening device but a “violet-ing” device, since it dampens low frequency components but amplifies high frequency components. Differencing generates an erratic time series when the time unit is not small as compared to serial correlations. The discontinuity caused by differencing can be described by a step function. Its Fourier transform is a delta function (Papoulis 1977); therefore, differencing may introduce a zero-frequency (dc) component. This often happens with trendy time series.

An alternative way is to find a smooth trend by fitting log-linear or polynomial functions. A difficulty is the choice of period boundaries in trend removing. This problem can be alleviated by the Hodrick–Prescott (HP) “trend smoothing” algorithm (Hodrick and Prescott 1997).

The HP filter is a linear transformation of the original time series [$X(t)$] into a smooth time trend series [$G(t)$] plus cyclic deviations from the trend by minimizing the following objective function

$$Min \sum [X(t) - G(t)]^2 + s \sum \{[G(t+1) - G(t)] - [G(t) - G(t-1)]\}^2 \qquad (7.1)$$

Deviations from $[G(t)]$ are considered as the cyclic component:

$$C(t) = X(t) - G(t)$$

Empirical time series can be decomposed into "smooth" growth series $[G(t)]$ and cyclic component $[C(t)]$. The characteristic period of HP short cycles depends on the penalty or smooth parameter s. s is chosen in such a way that the variance of the growth component is much less than that of the cyclic term (Hodrick and Prescott 1997). In practice, the recommended value of s is 400 for annual data, 1600 for quarterly data, and 14,400 for monthly data for US business cycle analysis (Chen 1996a).

The penalty term in equation (7.1) is the second difference in the growth series. When s goes to infinity, the growth trend is a linear function. For logarithmic data, log-linear detrending corresponds to the limiting case in HP decomposition. HP growth trends are less rigid than the log-linear function and HP cycles are less erratic than differencing. Certainly, HP growth trends provide little information about growth cycles and long waves, which are beyond the scope of NBER chronology. A more generalized algorithm of multi-level symmetric decomposer will be further developed to analyze multiple frequencies in business cycles (Chen and Qian 1993).

A typical example of economic time series is showed in Figure 7.2. The erratic feature of FDs series and the wavelike feature of HPc cycles are visible from their autocorrelations.

7.3.2 Correlation analysis of noise and cycles

Correlation analysis is capable of revealing the existence of deterministic cycles when we examine cyclic movements in serial correlations. We may define the decorrelation time Td measured by the lag length of the first zero in autocorrelations (Chen 1988a, 1993a). Usually, the time lags in correlation analysis are integers. Here, the fractal length of Td time is calculated from linear interpolation in the framework of continuous time.

The decorrelation period P_{dc} can be defined as following:

$$P_{dc} = 4\,\Delta t * T_d$$

where Δt is the time unit of the time series.

For deterministic cycles, P_{dc} is close to the characteristic period P_c measured by the peak in the power spectrum. For random signals, Td is very short with no implication of cyclic movement.

We can see that the FD filtered time series have a shorter Td or smaller P_{dc} as compared to HP filtered series (Table 7.1).

Among the empirical time series, GDPQ is the real gross domestic products in 1987 US dollars, LBOUTU is the non-farm output per hour; GCQ is the total consumption; GCDQ is the durable consumption; GPIQ is the domestic investment;

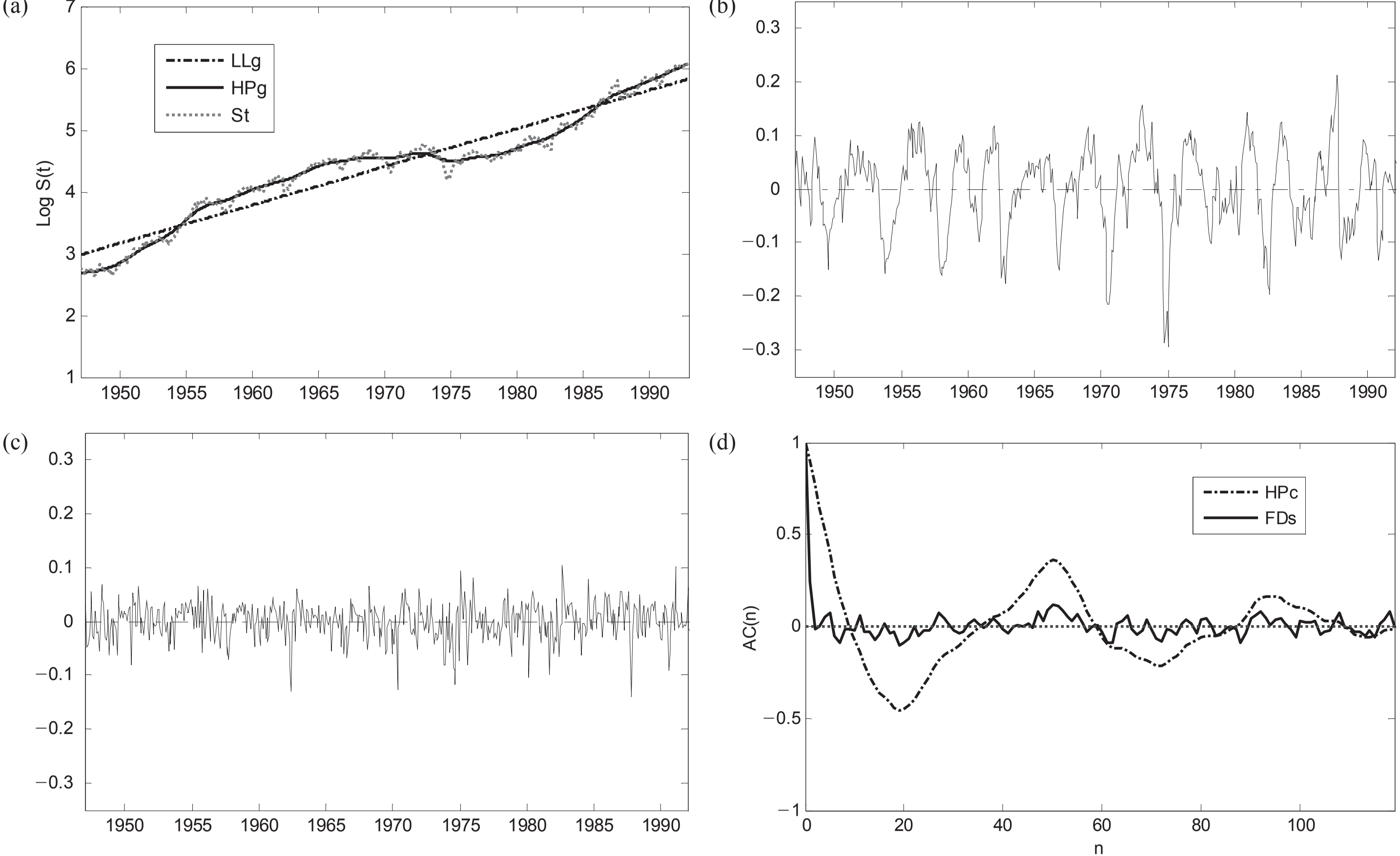


Figure 7.2 The logarithmic FSPCOM (the S&P 500 Stock Price Index) monthly data (1947–1992) (N = 552). (a) Log-linear trend and HP growth trend. (b) HPc cycles from the HP (Hodrick–Prescott) filter. (c) FDs series from the first differencing filter. (d) Autocorrelations of HP and FDs cycles.

Table 7.1 Correlation and variance analysis of filtered time series

Series	Δt	*Period*	*N*	λ	σ_{hp}	T_{hp}	σ_{fd}	T_{fd}
GDPQ*	Q	1947–1992	184	1600	0.0180	4.83	0.0102	3.51
LBOUTU*	Q	1947–1992	184	1600	0.0104	4.22	0.0081	3.40
GCQ*	Q	1947–1992	184	1600	0.0117	4.93	0.0077	3.72
GCDQ*	Q	1947–1992	184	1600	0.0547	4.95	0.0416	2.58
GPIQ*	Q	1947–1992	184	1600	0.0822	3.73	0.0535	2.71
FSPCOM*	M	1947–1992	552	14,400	0.0750	8.93	0.0340	1.95
FSDXP	M	1947–1992	552	14,400	0.3420	8.41	0.1670	1.84
FYGT10	M	1953–1992	480	14,400	0.6305	9.80	0.3198	1.73
FM1*	M	1959–1992	408	14,400	0.0116	11.03	0.0049	20.84
FM2*	M	1959–1992	408	14,400	0.0099	11.37	0.0034	24.87
GMYFM2*	M	1947–1992	552	14,400	0.0154	10.30	0.0073	4.99
LHUR	M	1948–1992	540	14,400	0.6398	9.38	0.2340	8.94
PZRNEW*	M	1947–1992	552	14,400	0.0103	11.99	0.0040	88.82
FYFF	M	1955–1992	456	14,400	1.2898	10.64	0.6377	1.98
FYCP90	M	1971–1992	264	14,400	1.3860	10.50	2.4630	1.79
EXRJAN	M	1959–1992	408	14,400	11.2700	9.70	4.7500	5.68

Notes
The time unit (Δt) is Q (quarter) for quarterly data and M (month) for monthly data; N, number of observations; λ, the HP parameter; σ, the standard deviation; T, the short version of the decorrelation time T_d (in Δt). Subscripts of hp and fd are for HP and FD series respectively. Data source is Citibase.

FSPCOM is the S&P 500 composite monthly index; FSDXP is the S&P common stock composite dividend yield; FYGT10 is the ten year Treasury Notes; FM1 is the Federal Reserve monetary supply M1 index; FM2 is the Federal Reserve monetary supply M2 index; GMYFM2 is the velocity of money; LHUR is the unemployment rate; PZRNEW is the consumer price index for all items; FYFF is the rate of Federal Funds; FYCP90 is the three month commercial paper rate; and EXRJAN is the exchange rate of Japanese yen vs. US dollar. All quantity data marked by the * symbol are in logarithm. The data source is the Citibase.

We should point out that the very long T_{fd} for FM1, FM2, and PZRNEW differenced data, which are caused by residual trends in first differenced data. These are examples why multiple differencing are often applied to remove trends in econometric analysis.

7.3.3 Characterizing the randomness and instability in the frequency domain

In a time series analysis, the degree of whiteness is often examined by its autocorrelations in the time domain. We will introduce some useful indicators of randomness and instability in the frequency domain.

Given a time series S(t), t = 1, 2,…, T, we can calculate its power spectrum R_i, i = 1, 2,…, M. We define γ as the degree of randomness of a time series in terms of the discrete-time information entropy γ: in the frequency domain:

$$\gamma = \frac{\sum p_i (\log_2 p_i)}{\psi}$$

$$p_i = \frac{R_i}{\sum_{i=1}^{W} R_i}$$

$$\psi = \log_2 W$$

Here, R_i is the power intensity of frequency i calculated from the power spectrum; p_i, the probability of frequency i; and W, the number of states in the frequency domain. ψ is the normalization factor which is equal to the maximum entropy of white noise, where

$$p_i = \frac{1}{W}.$$

In ideal cases, discrete-time information entropy γ is zero for periodic motion and one for white noise. The degree of randomness of color chaos or color noise will fall in between. In numerical tests, γ is less than 0.3 for periodic cycles, and larger than 0.9 for the Gaussian noise depending on the size of data.

From the time–frequency distribution $F(f, t)$, we can identify the peak frequency distribution $f(t)$ and calculate useful statistics to characterize peak frequency $f(t)$. For changing frequency of nonstationary time series, the characteristic frequency f_c is a function of time. The peak frequency $f(t)$ can be determined at each time intersection in a time–frequency representation. The characteristic frequency f_c can be measured by the mean value of the peak frequency. Its frequency instability can be defined by the standard deviation of the peak frequency.

We define ς as the degree of frequency instability measured by the percentage of white noise frequency bandwidth:

$$\varsigma = \frac{std[f(t)]}{B}$$

Here B = 0.5 for the full band window in spectral analysis. For stable periodic cycles, ς is near zero. For random process, ς is close to one. The frequency instability can be considered as a measure of internal randomness caused by frequency evolution over time. For example, a harmonic oscillator with wandering frequency may appear as random signals in Fourier spectrum, even though its deterministic nature can be seen from time–frequency analysis.

Similarly, we may also define the frequency variability ν as the percentage ratio of the standard deviation to the mean frequency.

$$\nu = \frac{std(f)}{mean(f)} * 100\%$$

We will use the above quantitative measures in studies of filter performance for mixed signals of noise and cycles.

7.3.4 Color residuals and time unit consistency

We use the FSPCOM time series to demonstrate the performance of FD and HP filter in studies of business cycles. WGQ spectrograms are given in Figure 7.3. The residual statistics under time–frequency representation are given in Table 7.2. The residual statistics in the frequency domain under different time units are given in Table 7.3. We can see that these residuals are far from white noise in spectral analysis.

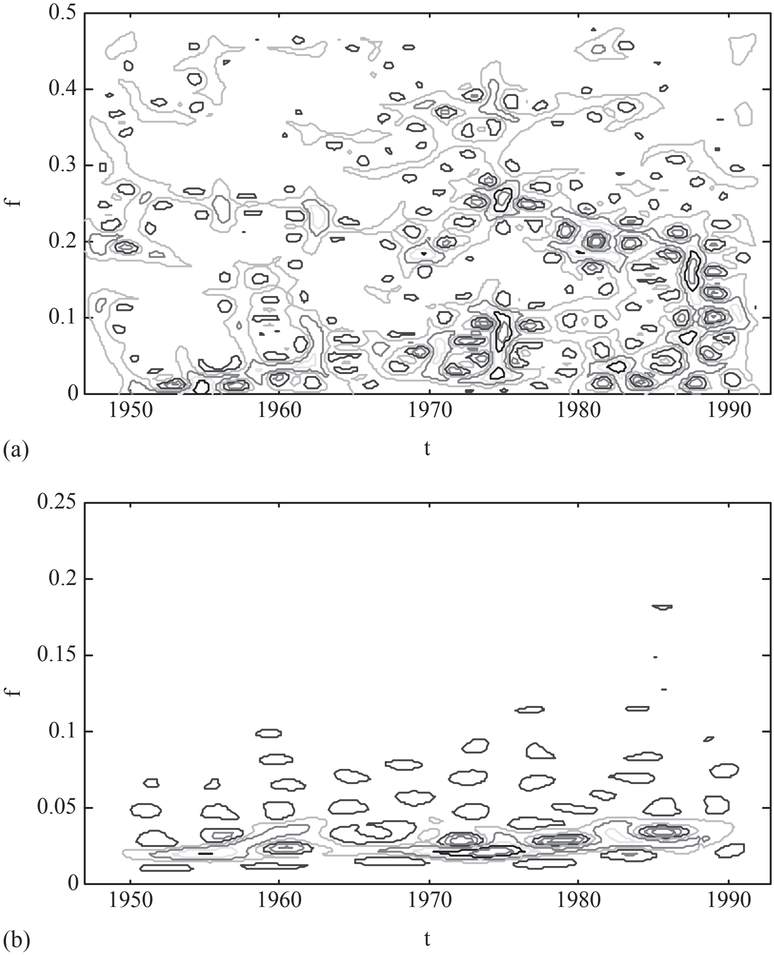


Figure 7.3 The WGQ spectrogram of the logarithmic FSPCOM (N = 552). (a) First differences. (b) HP cycles (λ = 14,400).

Table 7.2 Time–frequency analysis of FSPCOM filtered cycles

Filter	f_{mean}	*std(f)*	ς	ν	P_{mean}	P_{min}	P_{max}
HP (λ = 14,400)	0.0265	0.0057	0.0114	22	3.1	0.70	4.73
FD	0.0893	0.0886	0.1772	99	0.9	0.25	inf

Notes
Here, the time unit of periods is a year. The sampling time interval Δt is 1/12 of a year; std(f), the standard deviation of peak frequency over time; $f_c = f_{mean}$; $P_c = P_{mean} = \Delta t/f_{mean}$; P_{min} and P_{max}, the range of peak period over time; ς, the degree of frequency instability; and ν, the frequency variability (%).

Table 7.3 Spectral and correlation analysis with changing time unit

Name	Δt	*Filter*	γ	P_c *(yrs)*	T_d *(Δt)*	P_{dc} *(yrs)*	*std(t)*
FSPCOM	M	FD	0.8895	inf	1.9	0.6	0.0338
	Q_f	FD	0.8831	inf	1.4	1.4	0.0707
	Q_v	FD	0.8384	inf	2.0	2.0	0.0578
	A_f	FD	0.7075	inf	0.1	0.4	0.1136
	A_v	FD	0.6475	inf	1.5	6.1	0.0895
	M	HP (= 14,400)	0.5501	3.6	8.9	3.6	0.0752
	Q_f	HP (= 1600)	0.7366	4.0	3.5	3.5	0.0892
	Q_v	HP (= 1600)	0.6659	3.8	3.5	3.5	0.0834
	A_f	HP (= 400)	0.7982	3.8	1.8	7.1	0.1161
	A_v	HP (= 400)	0.6592	5.1	1.7	6.7	0.0863

Notes
Here, γ is the frequency information entropy indicating the degree of randomness; P_c, the characteristic period in power spectrum; T_d, the decorrelation time; Pdc, the decorrelation period and std(t), the standard deviation in time domain.
Two methods of constructing a time series in a larger time unit are used. Q_f (A_f) series are constructed by picking up the figure of the final month (quarter) in the season (year). Q_v (A_v) series are constructed by averaging value in the season (year).

We can see that the FD filter does not provide a consistent picture of a detrended series. The frequency information entropy indicates that the FD residuals are not white. The band width of the FDs is less than 20 percent of white noise. There is a strong component at near zero-frequency caused by the discontinuous nature of differencing time series. The FD filter fails to produce a consistent picture under the changing time unit. Changing the time unit will change the length of decorrelation time and the magnitude of variance. The FD filter plays a destructive role in testing the cyclic signals. The time–frequency representation shows that noisy signals of high frequencies are strongly amplified, while the deterministic cycles in the range of business cycles are hard to recognize from the FD filtered series. The negative effects of the FD filter are not visible for pure deterministic or pure stochastic signals, but are quite severe for noisy data with growth trends.

In contrast, the HP filter provides a consistent picture of persistent cycles from an economic time series when the sampling rate is large enough to detect business cycles (quarterly or monthly, but not annual data). The characteristic periods for economic aggregates are highly stable, since they are slightly changing over time. The frequency variability of HPc cycles is as low as less than 3 percent. The characteristic period P_c from spectral analysis and decorrelation period P_{dc} from correlation analysis are remarkably close. This is strong evidence of deterministic cycles. The magnitude of the characteristic period P_c is essentially invariant under the changing time unit. Time unit consistency paves the way for refined measurement and generalized theory.

Previous claims of unit roots in aggregate data are produced from fitting annual or quarterly data to low-order ARMA (autoregressive and moving average) models (Nelson and Plosser 1982; Campbell and Mankiw 1987). There is no evidence of the unit root process since FD-filtered quarterly and monthly data are far from white under spectral representation (Chen 1993c).

7.4 Frequency patterns and dynamical changes in business cycles

The HP filtered economic time series show clear evidence of persistence cycles in the time scale of business cycles defined by NBER documentation (Zarnowitz 1992). We will further examine their frequency patterns and structural changes by time–frequency analysis.

In econometric modeling and business-cycle theory, variance-correlation analysis is the main tool in characterizing volatility and propagation mechanism (Kydland and Prescott 1990). Structural changes are described by parameter changes in parametric models (Perron 1989; Friedman and Kuttner 1992). The time–frequency representation provides a new tool in observing dynamical patterns in business cycles.

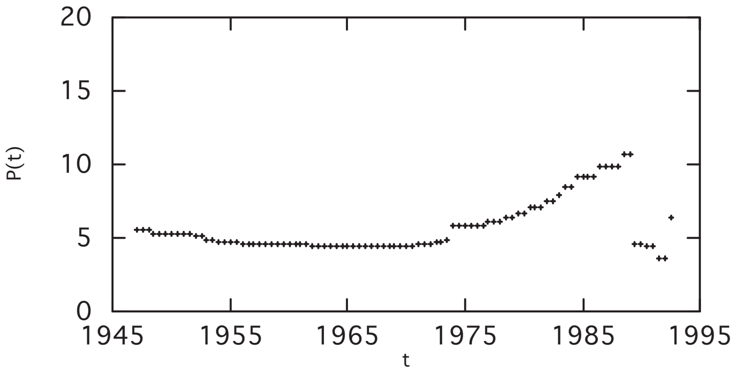
7.4.1 Frequency stability and structural flexibility

We tested a wide range of aggregate data. Most of them have distinct color, or characteristic frequency. The empirical results of 16 economic aggregates from time–frequency analysis are given in Table 7.4. The period evolution for general indicators, such as GDPQ, LHUR, and LBOUTU are shown in Figure 7.4.

We find that the only frequency break of GDPQ HPc cycles was caused by the first oil price shock in 1973. This observation provides complementary support to trend-shifting argument based on the parametric test (Perron 1989).

However, the oil price shock only had a minor impact on most macroeconomic indicators. For LHUR HPc cycles, the first frequency shift occurred within the Korea War, the second and more dramatic change appeared in early 1980s. For LBOUTU, a significant change happened in the early 1980s. Most economic indicators show more complex patterns of frequency evolution in history.

Examining the frequency stability of HPc cycles under a time–frequency representation, the characteristic frequency of FSPCOM (S&P500) is most stable, while those of FYCP90 and EXRJAN are most variable. The other aggregates



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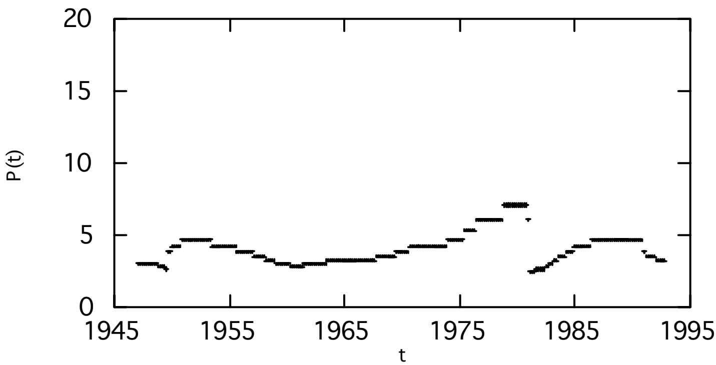

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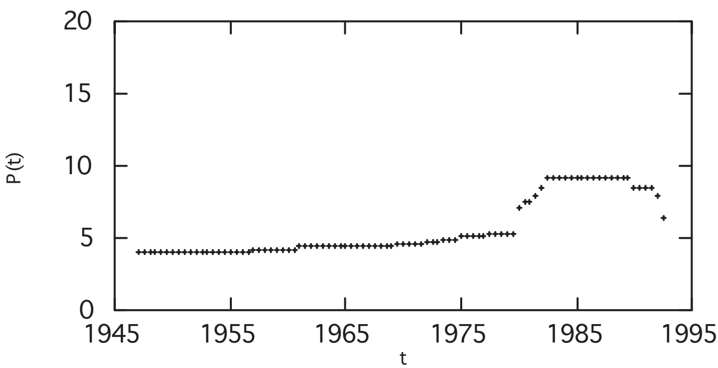


(c)

Figure 7.4 Period evolution of general indicators. (a) GDPQ (the real gross domestic products) HP cycles (N = 184). (b) LHUR (the unemployment rate) HP cycles (N = 540). (c) LBOUTU (the labor productivity) HP cycles (N = 184).

Table 7.4 Frequency stability and variability of HP short cycles

Series	Δt	*Period*	*N*	*Pdc*	*Pc(yrs)*	ν *(%)*
GDPQ	Q	1947–1992	184	4.8	5.4	23
LBOUTU	Q	1947–1992	184	5.1	4.2	26
GCQ	Q	1947–1992	184	4.4	4.9	47
GCDQ	Q	1947–1992	184	4.4	5.0	49
GPIQ	Q	1947–1992	184	4.4	3.7	34
FSPCOM	M	1947–1992	552	3.1	3.0	22
FSDXP	M	1947–1992	552	2.9	2.8	37
FYGT10	M	1953–1992	480	3.1	3.3	37
FM1	M	1959–1992	408	3.7	3.6	46
FM2	M	1959–1992	408	3.9	3.3	46
GMYFM2	M	1947–1992	552	3.8	3.4	32
LHUR	M	1948–1992	540	3.9	3.1	23
PZRNEW	M	1947–1992	552	4.0	4.0	27
FYFF	M	1955–1992	456	3.6	3.5	51
FYCP90	M	1971–1992	264	3.1	3.5	73
EXRJAN	M	1959–1992	408	3.0	3.2	57

Notes
Here, Pdc is the decorrelation period from correlation analysis; Pc, the characteristic period from time–frequency analysis and ν and frequency variability (see Figures 7.5–7.6).

are in between. There are several interesting observations to business cycle studies.

First, the frequency stability of economic indicators is remarkable. The variability of frequency is less than 80 percent. The band width of S&P 500 index is only about 20 percent of white noise. Specifically, monetary movements cannot be oversimplified as pure external shocks because money indicators also have stable characteristic frequencies. The monetary velocity is more stable than FM2 and the long-term interest rate FYGT10 is more stable than the short-term interest rate.

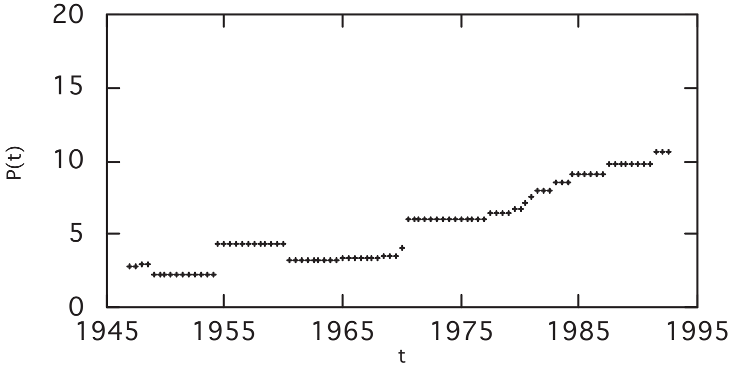
Second, these characteristic frequencies have the similar range of magnitudes, but a distinctive pattern; therefore they are nonlinear oscillators in nature, because a linear combination cannot change the characteristic frequencies.

Third, the stability and flexibility of the characteristic frequency under constant shocks cannot be explained by the Frisch-type linear oscillators (Frisch 1933). High-dimensional nonlinear oscillators are needed to describe persistent cycles observed from economic data.

7.4.2 Frequency evolution and pattern classification

Econometric modeling is used to treat economic aggregates as homogeneous random variables. Under time–frequency representation, we find hard and soft cycles from their distinct patterns of frequency evolution (Figure 7.5).

Consumption, investment, and productivity are examples of hard cycles. They have piece-wise flat regimes, a reflection of stability and rigidity in frequency



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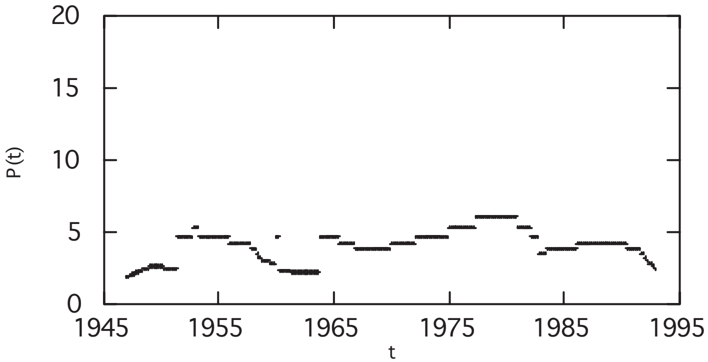

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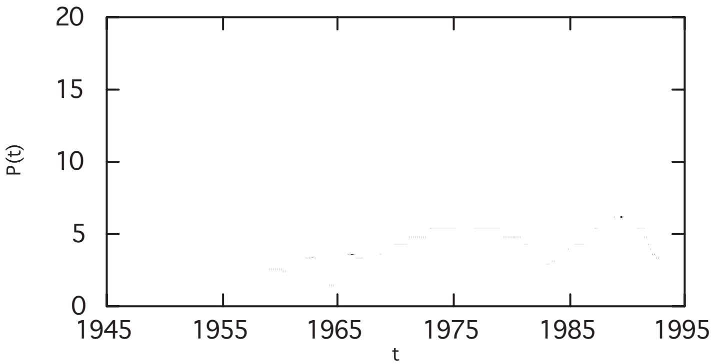
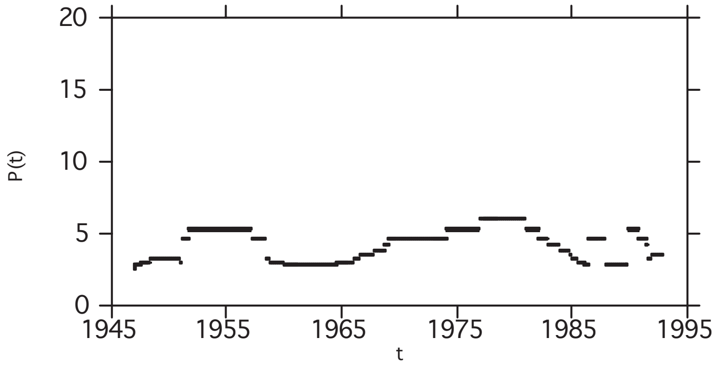


(c)

Figure 7.5 Period evolution of hard and soft cycles. (a) GCDQ (the real durable consumption) HP cycles (N = 184). (b) GMYFM2 (the monetary velocity) HP cycles (N = 552). (c) FM1 (the money supply M1 index) HP cycles (N = 408).

continued



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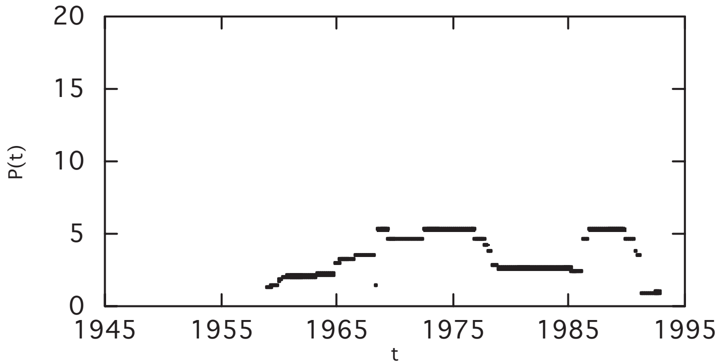


(e)

Figure 7.5 (d) PZRNEW (the consumer price index) HP cycles (N = 552). (e) EXRJAN (the Japanese/US exchange rate) HP cycles (N = 408).

domain. Hard cycles are more stable against small changes but vulnerable under dramatic shocks. Hard cycles behave like an autonomous subsystem such as the circulatory system and digestive system in humans. It is conceivable that consumption, investment, and technology have their own dynamics.

Stock market indexes, monetary velocity, money supply, the consumer price index, interest rate, and exchange rate are examples of soft cycles. Soft cycles tend to move together since they have similar patterns in time–frequency space. One possible cause is that they are correlated by monetary policies. A new kind of frequency co-movements reveals a close interaction between stock market, money market, and economic performance.

We can further identify subgroups of economic indicators based on their pattern of similarity in frequency evolution. For example, both GDPQ and LBOUTU are insensitive to most historical events. GCQ, GDPQ, and GPIQ have similar rigidity and stability. Two stock market indicators, FSPCOM and

FSDXP, and the long-term interest rate FYGT10 have almost the same pattern, even though their frequencies are not the same. The pairs of FYFF and FYCP90 also move together during frequency shifting. These observations provide useful information about the interacting mechanism and propagation dynamics. Examination of the time–frequency pattern will be a valuable guidance for business cycle modeling.

For example, consumption and investment have closer interactions than income and price.

Monetary movements have less an impact on stock market and the long-term interest rate than on the short-term interest rate.

The role of money is not neutral in business cycles. The frequency pattern of monetary indicators is similar to that of the consumer price index and the unemployment rate but more variable than real income, investment, and consumption. Unlike seasonal changes in weather, government and monetary authority are integrated players in economic dynamics. Monetary movements have complex structures.

The real GNP serves as an anchor in real business cycle modeling (Kydland and Prescott 1990). However, real GNP is not a sensitive indicator for structural changes. The monthly data of the unemployment rate can be a better barometer of business cycles and structural changes.

7.4.3 Breaking points and propagation mechanism

The breaking points in frequency evolution provide explicit information about the propagation mechanism. We can observe propagation speed and delay process by reviewing historical events.

In econometric exercises, the issue of persistent shocks is not clear under regression analysis (Christiano and Eichenbaum 1990). Impacts of historical shocks vary greatly under time–frequency representation. For example, two pairs of economic aggregates, stock market indexes of FSPCOM and FSDXP, the Federal fund rate FYFF, and the short-term interest rate FYCP90, behave like synchronous cycles. In contrast, the frequency pattern of the long-term interest rate FYGT10 almost duplicates the pattern of stock market indicators. But the frequency hysteresis lasted about six years during the Vietnam War and oil price shocks (Figure 7.6).

Exceptional variability in Federal Fund rates and short-term interest rates are visible in Figure 7.6. It is known that the pattern of monetary movements had changed greatly in the 1980s (Friedman and Kuttner 1992). The puzzling issue of "missing money" and other anomalies can be explained away by adding more variables, such as long-term and short-term interest rates, in the error-correction model (Baba *et al.* 1992). This approach is skeptical under time–frequency analysis since variables with different frequency responses cannot be easily put together in linear models.

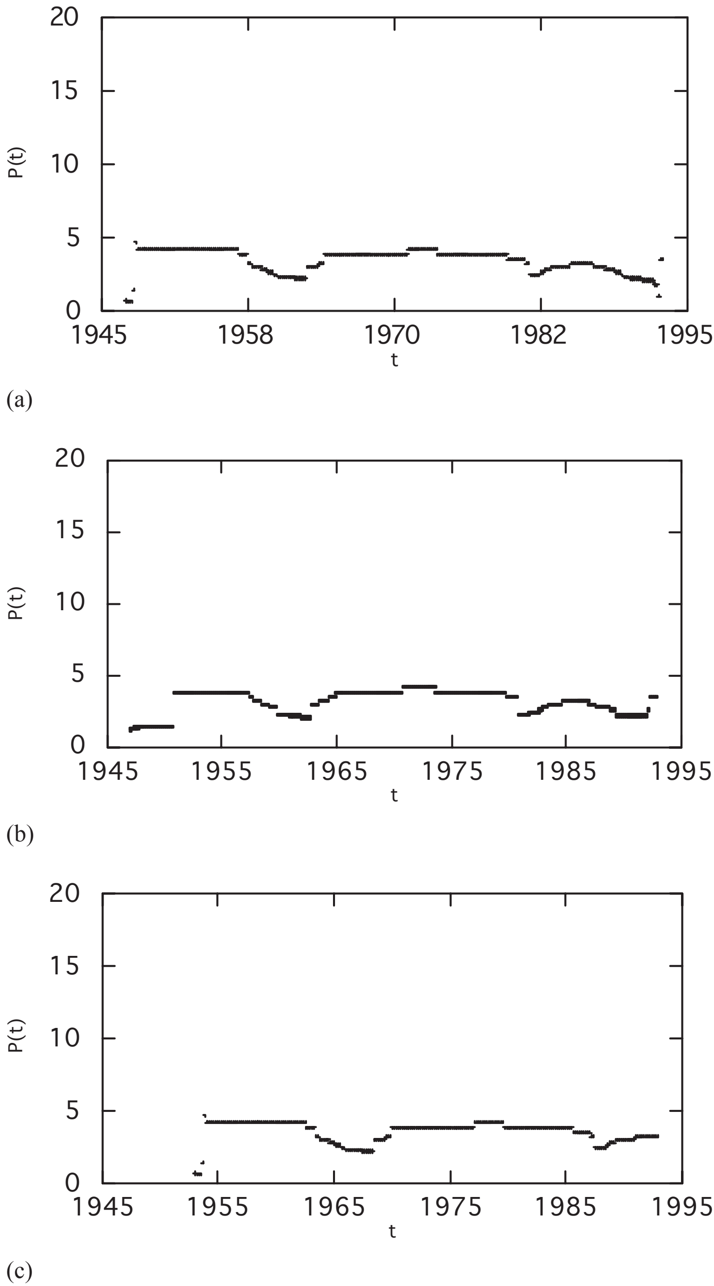
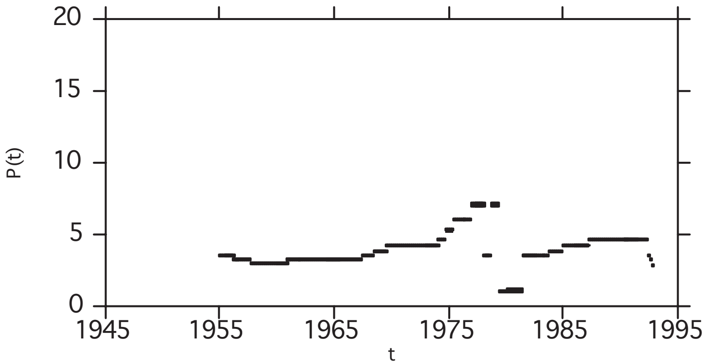


Figure 7.6 Synchronous cycles and frequency hysteresis. (a) FSPCOM (the S&P 500 stock index) HP cycles (N = 552). (b) FSDXP (the S&P stock dividend yield) HP cycles (N = 552). (c) FYGT10 (the ten year treasure notes rate) HP cycles (N = 480).



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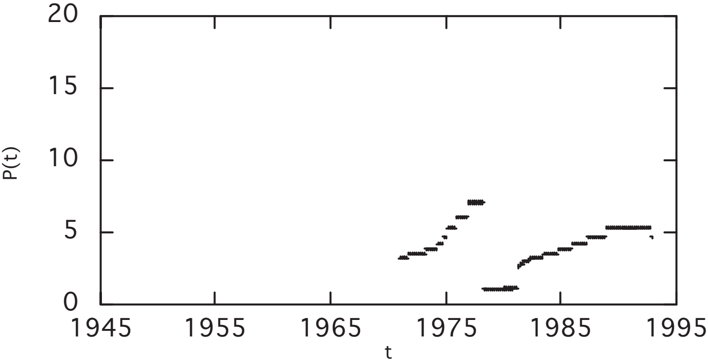

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Figure 7.6 (d) FYFF (the rate of Federal Funds) HP cycles (N = 456). (e) FYCP90 (the three month commercial paper rate) HP cycles (N = 264).

7.4.4 Oil shocks, stock market crash, and the Vietnam War

The extraordinary resilience of market economies can be revealed from the insignificance of the first oil price shock in October 1973 and the stock market crash in October 1987. Both events generated only slight changes of characteristic frequencies for most economic aggregates.

We may have a closer look at frequency evolution in observing historical events (Figures 7.6a, 7.6b). Before the oil price shock in October 1973, the characteristic period of stock market indicators was stabilized at the level of 4.26 years since 1971. After the oil price shock, the characteristic period of HP cycles changed to 3.86 years. Obviously, the oil price shock was the external cause of frequency change in the stock market.

This may not be the case for the stock market crash in October 1987. There was a long swing of frequency during the 1981–1990 periods. For FSPCOM and

FSDXP HP cycles, their characteristic period of 3.28 years lasted for two years (1985–1986). Then, their characteristic period slightly changed to 3.05 years for FSPCOM (January–December 1987) and FSDXP (January–October 1987), and 2.84 years thereafter. The stock market crash happened at the end of the ten month "frequency shift." There was a two month delay for FSPCOM after the stock market crash. This suggests that the stock market crash is the end of an internal bubble instead of external shocks.

The interesting thing is that the political economy of wars and arms races left a much stronger fingerprint in the time–frequency representation. The most significant changes of the frequency pattern happened in three periods: US–Soviet arms and space races during 1958–1962, the escalation of the Vietnam War during 1965–1972, and the so-called Reagan revolution in the 1980s. Not only fiscal and monetary policy, but also industrial policy, tax policy, and military program, may have notable impacts on structural changes of the US economy.

7.5 Theoretical implications of persistent cycles and economic instabilities

There is no question that external noise and measurement errors widely exist in economic data. The question is whether some regularity is observable from an empirical time series. The answer is yes.

Like a telescope in astronomy or a microscope in biology, time–frequency analysis opens a new window of observing evolving economies. The most enlightening result in business cycle studies is the discovery of persistent cycles, i.e., self-generating cycles from economic aggregates. These cycles are nonlinear in nature with remarkable resilience and flexibility like living beings. This discovery provides a new perspective to business cycles. Traditionally, the economic order is characterized by negative feedback and equilibrium (steady) states. The new role of persistent cycles challenges the linear framework of economic dynamics. We need to re-examine the implications of complexity and instability in business cycles.

7.5.1 Characteristic frequencies and endogenous cycles

The existence of characteristic frequencies in economic movements has profound implications in business-cycle theory.

Economic movements, like organisms, have their distinct time rhythms. Different economic factors move with different speeds and different frequencies. In this sense, economic aggregates have their "personalities" and they are not all alike in frequency patterns. The pattern recognition in economic dynamics will pave the way for economic diagnostics and policy valuation.

Changing patterns of characteristic frequencies of business cycles reveal internal sources of economic shocks, such as military expenditures and tax policies. Economic interactions are highly correlated and are an essential nature of collective phenomena. The impact of monetary shocks and technology shocks can be better understood if we know their own dynamics. There is no absolute dividing line between internal and external shocks. Nonlinear interaction, rather than linear causality, provides a better picture for understanding the historical experience of economic evolution.

We should point out that the popular name of "chaos" is somewhat misleading because of its negative image of irregularity and disorder. That is why we suggest the term of "complex cycles" or "persistent cycles" for deterministic chaos in continuous time. We also prefer the name of "color chaos" to white noise. Unlike controlled experiments in natural science, complex chaotic cycles may not be "verified" in economic dynamics, but can be observed through empirical patterns, such as time–frequency representation. Like calculus for classical mechanics, Riemann geometry for gravitation theory, new mathematical tools, such as nonlinear dynamics and nonstationary time series analysis, are critical to the advancement of economic dynamics.

7.5.2 Time scale and observation reference in measurement and theory

Econometricians often argue that the measurement method of economic indicators (such as annual or daily data) demands the discrete-time algorithm (Granger and Teräsvirta 1993). These technical arguments ignore fundamental issues of time scale in any dynamical theory (Chen 1993a).

In the history of empirical science, many theoretical controversies can be settled by refining measurements. Whether economic laws of motion (if they exist) are invariant under changes of time units is a fundamental issue in economic dynamics. For example, if econometric tests of long-run economic relationship, such as unit roots or linear causality, succeed for annual or quarterly data but fails for monthly data, the validity of underlying economic theory would be questionable (Lütkepohl 1991).

The most visible pattern of economic movements is the recurrent feature of business cycles in the time scale of several years. Regression analysis is more comfortable with annual data than monthly data, since serial correlations can be easily explained by stochastic models with few lags. However, annual data is helpless for spectral analysis. Measurement precision does matter in empirical economic studies. If dynamic patterns change with the time scale, such as the patterns of the stock market movements during a trading day may differ from the patterns during a business cycle, we should change the dynamic model and not just the time unit.

The degree of mathematical complexity is associated with computational reliability. Conventional discrete-time ARMA models have poor resolution because of the extremely low computational degree of freedom. A better resolution of the WGQ spectrogram comes from new representation reconstruction in terms of a two-dimensional Gaussian lattice instead of a one-dimensional polynomial fitting.

The differencing operator serves a poor reference base in business cycle studies. From the view of resource constraints, the FD framework implies no history in economic dynamics, if level information is not relevant to economic dynamics. Most economic variables, including the government budget, credit limits, wealth, capital stock, savings, inventory, consumption, and production, are measured by levels. Rich patterns in HPc cycles indicate that both flow and level variables matter in economic dynamics.

We recommend the HP filter as a better device in trend–cycle decomposition because the HP filter produces consistent measurement and historical patterns through time–frequency analysis.

7.5.3 Dynamical instability and information ambiguity

In the history of science, some thought experiments once dramatically shaped theoretical thinking in fundamental issues. Notable examples are: Maxwell's demon in thermodynamics, the uncertainty principle in quantum mechanics, and the Friedman paradox on the non-existence of destabilizing patterns in speculative dynamics.

Friedman asserts that no predictable pattern can exist in the market beyond a short time horizon because rational arbitrageurs (Friedman's spirits) will rapidly wipe out any destabilizing traders from the market (Friedman 1953b). This is the essence of the efficient market hypothesis and the main argument against the possible existence of market regularity. Actually, Friedman's spirits behave much like Maxwell's demon in equilibrium thermodynamics, although their purposes are just the opposite (Chen 1993a; Brillouin 1962).

In addition to information costs and financial constraints (Grossman and Stiglitz 1980; De Long *et al.* 1990), there are more serious barriers for arbitrageurs' action.

First, the observational reference for economic equilibrium and market fundamentals are simply not well-defined operationally. Friedman's argument may be valid for an island economy without growth and nonlinear interactions among residents, but not valid for an open economy with growth and collective actions.

Second, the problem of information ambiguity is more fundamental than information scarcity from the point of view of time–frequency analysis. The implications of the information flow can only be understood in terms of a historical context, such as the case of linguistic analysis. It is impossible to judge economic trends from uncorrelated shocks. Investment hysteresis in the range of two to four years can be understood by the value of waiting under uncertainty (Dixit 1992). The time delay in information analysis and decision making is a main source of overshooting and inertia.

Third, dynamical instability and bounded rationality set fundamental limits to economic forecasting. Nonlinearity, nonstationarity, and the uncertainty principle in information analysis, all contribute to complexity and indeterminacy in economic forecasting (Prigogine 1993; Chen 1993a). Friedman's argument implies that irrational speculators are sure losers. This would be true only for simple dynamical systems when market movements could be perfectly predictable. The extreme cases of complete unpredictability of random walks and perfect predictability of harmonic cycles are unrealistic features of linear dynamics. The modest behavior of nonlinear oscillators fills in the gap between the two extremes.

In short, rational arbitrageurs on average cannot eliminate cyclic patterns, even in the long run. We can forecast general economic trends including their mean period and variance, but we cannot predict time path and turning points simultaneously even when we know of some pattern of economic dynamics. There are no sure winners or losers on the speculative market because of the complex nature of business cycles. The uncertainty principle in signal processing provides an alternative explanation why price unpredictability does not imply market efficiency. There is still large room for strategic behavior and herd (irrational) behavior in financial market.

7.7 Brief conclusion: evolving economy and complex dynamics

Now, we have a better understanding of why business cycles have been well documented by the NBER approach, but are hard to characterize by statistical analysis based on a stationary process (Zarnowitz 1992). The existence of growing economic trends and structural changes needs new analytical tools for nonlinear and nonstationary process. Time–frequency representation and the HP trend–cycle decomposition pave the way to study persistent cycles from empirical economic data.

The characteristic frequencies of economic variables provide rich information about internal dynamics and structural changes. Our integrated approach in empirical analysis and theoretical framework reveals the important role of time scale, observation reference and pattern recognition in business cycle studies.

Acknowledgments

Our interdisciplinary research in nonlinear economic dynamics is a long-term effort in the studies of complex systems supported by Professor Ilya Prigogine. The author wants to thank Profs. Heather Anderson, William Barnett, Clive Granger, Finn Kydland, Paul Samuelson, Michael Woodford, Victor Zarnowicz, Arnold Zellner, and Dr. Kehong Wen for their stimulating discussions and valuable suggestions. Specifically, the term of persistent cycles was suggested by Finn Kydland. Financial support from the Welch Foundation and IC^2 Institute is gratefully acknowledged.

Part III

Micro interaction and population dynamics

Learning, communication, and market share competition

8 Origin of division of labor and stochastic mechanism of differentiation[1]

8.1 Introduction

It is recognized that social evolution takes place in the context of a nonequilibrium world. But mathematical models in social sciences have in the past been dominated by the equilibrium paradigm. Today, a new methodology and new paradigm is appearing in nonequilibrium physics and chemistry (Prigogine and Stengers 1984). Its impact on social sciences is increasing (Allen 1982).

In this short chapter, we will discuss three simple models of nonequilibrium process in social phenomena. In section 8.2, we first introduce the behavioral factor in the learning process and the cultural trait in a competition model. We find a trade-off between security and development or stability and variability. This sheds some light on the differences between the Occidental and Oriental culture and the origin of division of labor in history. In section 8.3, we discuss the stochastic mechanism for the breakdown of Gaussian distribution. We first discuss a stochastic model of multi-staged development. Its initial and final state is a Gaussian distribution, but a multi-humped distribution appears during the transition stage. We also discuss the evidence for this stochastic mechanism in social differentiation. Finally, we give an ideal case of social bifurcation.

8.2 A behavioral model in learning competition: the origin of division of labor

Why is there a striking contrast between the Occidental and Oriental cultures? Why did science and capitalism emerge in Western Europe but not in China, India, Islamic, or other civilizations? Modern economics seems to lack working economic models about the origin of division of labor. In theoretical biology, the outcome of competing species essentially depends on resources and environment (Maynard Smith 1974). There is no link between changes in environment and adaptation from animal or human behavior.

It is realized that the culture factors play an important role in the origin of capitalism and sciences (Weber 1930; Whorf 1956). For example, Kikuchi is greatly aware of differences in the degree of "individualism" existing in the Eastern and Western culture. He suggests a one-dimensional model of degree of individualism, such as an axis ranging from highly individualistic European countries and the US at one extreme to the society of honey bees at the other (Kikuchi 1981). We will discuss this point from the view of learning process. We introduce a simple behavioral or cultural trait to study the mechanism of division of labor. First, we will study the modified information diffusion model for one species, and then we will consider learning competition, a model with two species.

8.2.1 An information diffusion model

Let us consider an information diffusion process without a central information source. We assume:

$$\frac{\partial n}{\partial t} = kn(N-n) - rn\left(1 - \alpha\frac{n}{N}\right) \tag{8.1}$$

Here N is population size, n is the number of knowers, $(N - n)$ is the number of learners, k is the growth rate, r is the removal rate. The last term is the removal rate or forgetting rate. Its form differs from the conventional constant loss rate (Bartholomew 1976). We may consider r as the measure of learning ability or degree of difficulty in learning a new technology.

Here we introduce a new factor α, the degree of sensitivity. If $\alpha > 0$, it is a measure of strangeness aversion. When few people accept the new information, the removal rate is large. When most people accept it, the forgetting rate decreases. This is the characteristic of conservatism. On the contrary, if $\alpha < 0$, this term is a measure of adventure loving. The absolute value of α is less or equal to unity. Different α represent different behavior or cultures, such as, social or solitary animals, conservative or progressive cultures. We easily find the equilibrium solution to equation (8.1):

$$n^* = N\left(1 - \frac{r}{kN}\right) / \left(1 - \frac{\alpha r}{kN}\right)$$

We see that

$$n^*_{\alpha<0} < n^*_{\alpha=0} < n^*_{\alpha>0}$$

If we have a fluctuating environment, we may consider the following stochastic equation:

$$\frac{\partial x}{\partial t} = kx(N-x) - rx\left(1 - \alpha\frac{x}{N}\right) + \sigma kx\xi(t) \tag{8.2}$$

Here x is a random variable, $\xi(t)$ is white noise with zero mean and unit variance, σ is the variance of white noise.

It is easy to find the extrema of the stationary probability density of the

Fokker–Planck equation obtained from (8.2) (Horsthemke and Lefever 1984). They are:

$$x_m = N\left(1 - \frac{r}{kN} - \frac{k\alpha^2}{2N}\right) \Big/ \left(1 - \frac{r\alpha}{kN}\right) \quad \text{when } \sigma < \sigma_c$$

$$x_m = 0 \quad \text{when } \sigma < \sigma_c$$

where

$$\sigma_c^2 = \frac{2}{k}\left(N - \frac{r}{k}\right)$$

We may compare two species: one is conservative in learning ($\alpha_1 > 0$) and another is progressive ($\alpha_2 < 0$). For conservative species, their steady size n_1 is larger. So, in order to maintain the same population size, they need smaller resource. And for progressive species n_2, they need larger subsistence space. For stability against fluctuating environment, the conservative one is more stable than the progressive. It is especially true if there is some survival threshold population (Zurek and Schieve 1982). But when new information comes, the conservative species has less potential to absorb new technology than progressive, if the learning ability is limited for every individual.

8.2.2 A learning competition model

Now we consider the learning competition model for two species with different cultures.

$$\frac{\partial n_1}{\partial t} = k_1 n_1 (N_1 - n_1 - n_2) - r_1 n_1 \left(1 - \alpha_1 \frac{n_1}{N_1}\right)$$

$$\frac{\partial n_2}{\partial t} = k_2 n_2 (N_2 - n_2 - n_1) - r_2 n_2 \left(1 - \alpha_2 \frac{n_2}{N_2}\right)$$

Here n_1, n_2 are knowers in species one and two respectively.

We may rewrite the equation as follows:

$$\frac{\partial n_1}{\partial t} = s_1 n_1 (M_1 - n_1 - \beta_1 n_2)$$

$$\frac{\partial n_2}{\partial t} = s_2 n_2 (M_2 - n_2 - \beta_2 n_1) \qquad (8.3)$$

Here M_i, s_i, β_i are the effective carrying capacity of resources, effective growth rate and effective competition coefficient respectively. And i, j is one or two.

We have

$$M_i = \left(N_i - \frac{r_i}{k_i}\right) / \left(1 - \frac{\alpha_i r_i}{k_i N_i}\right)$$

$$s_i = k_i \left(1 - \frac{\alpha_i r_i}{k_i N_i}\right)$$

$$\beta_i = 1 / \left(1 - \frac{\alpha_i r_i}{k_i N_i}\right)$$

Note: here we may have asymmetric overlap coefficients β_i when $\beta_1 \neq \beta_2$. β_i may larger than 1 when α_i is larger than zero. These results differ from the conventional competition equations (Nicolis and Prigogine 1977).

From (8.3), we find the condition for coexistent species. That is

$$\beta_1 M_2 < M_1 < M_2 / \beta_2$$

Or:

$$\left(1 - \frac{\alpha_1 r_1}{k_1 N_1}\right)\left(1 - \frac{\alpha_2 r_2}{k_2 N_2}\right) > 1$$

We immediately find that two progressive species will co-exist, but two conservative species cannot co-exist. When their competition has overlap on some resource, such as arable land, the only result is one replaces the other. It is the story repeatedly occurring in a traditional peasant society. Division of labor cannot emerge in a conservative culture.

If a progressive species competes with a conservative one, the survival strategy for progressive species is to improve its learning ability (to have smaller r or larger k) to achieve some threshold. If we consider capitalism as a culture of adventure loving, then we may reach the similar conclusion as economist Schumpeter that innovation is vital for capitalism in the competition between East and West (1950). Once innovations stop, capitalism will lose the game in the competition for existing resources.

If $r_1 \neq r_2$ and $\alpha_1 \neq \alpha_2$, there are variety of possibilities for competing species, therefore, we have a diversified world.

We may also study the stability against a fluctuating environment in terms of coupled Fokker–Planck equations. It is already known that the stability of a two co-existent species system is less stable than a single one (May 1973). Or we can say that a monolithic society is more stable than a pluralistic one, although pluralistic society enjoys more social wealth than the monolithic has. There is a trade-off between security and development or between stability and diversity (May 1974a, b). Division of labor has its benefit and cost.

Based on our model, we may discuss the evolutionary tree of social history. Clearly, it is a two-way evolution towards simplicity or complexity, depending on the environment and the structure of the system. We might also speculate why capitalism emerged in the West and not in the East.

8.3 The stochastic mechanism for the breakdown of Gaussian distribution in social differentiation

The Gaussian distribution is widely used in sciences. Because it is simple in application, we only need two parameters, the mean value and variance, to characterize a stochastic system. The peak evolution of Gaussian distribution generally follows the solution of corresponding deterministic equation (Reichl 1980). The limitation of the Gaussian distribution lies in the fact that it is a simplified model of near an equilibrium system. When fluctuations are very large, the mean value becomes a meaningless concept. In order to understand the mechanism of multi-humped distribution, it is necessary to go beyond the limits of the equilibrium dynamics.

We first give a numerical example of multi-humped distribution. Then we discuss an ideal case of bifurcation in social phenomena.

8.3.1 A stochastic model of multi-staged growth

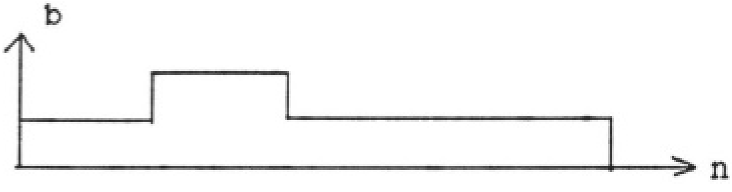
An early study of long tail or dual hump of distribution was done in the epidemic model (Levin 1978). Recently, the work in explosion model found multi-humped distribution of fluctuations during the transition stage (Frankowiz and Nicolis 1983). Here we consider a general model of pure birth process; the master equation is given as follows:

$$\frac{\partial P(n,t)}{\partial t} = b(n-1)P(n-1,t) - b(n)P(n,t)$$

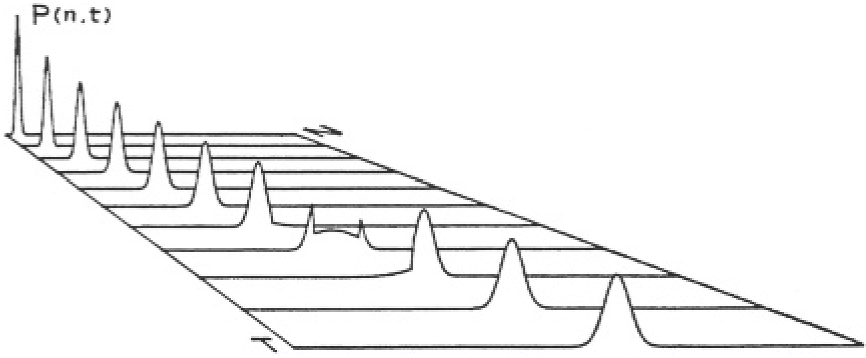
Note $P(n, 0) = \delta(1)$ and $b(0) = b(N) = 0$. Here n can be regarded as population size or state number. The transition probability from n to n + 1 in time t to $t + \Delta t$ is b(n). If the birth rate b(n) is not a smooth function but a piece-wise one, which is commonly seen in multi-staged development process (Piaget 1971; Rostow 1990), we will easily generate a multi-humped distribution function during the transition stage. A numerical example of time evolution in distribution function is shown in Figure 8.1

This simple model reveals the stochastic origin in social differentiation during multi-staged development. Since any social system has finite size N, the law of large numbers cannot rule out the existence of non-Gaussian distribution in social phenomena.

The stochastic mechanism of differentiation is very important to understand social development. Suppose we do a survey of a group of children, examining their physical and psychological development. We will certainly find deviations



(a)



(b)

Figure 8.1 Time evolution of probability distribution in pure birth process (a) Three staged birth rate in development: b = 1.0 for 350 < n < 450, otherwise, b = 0.3. (b) Multi-humped probability distribution during time evolution. N = 1000. The time scale depends on the constant of birth rate.

from average behavior. Some children may advance far ahead, and some fall far behind. Social scientists might attribute these differences to some genetic, socio-economic or cultural factors, because they assume the normal development will follow the Gaussian distribution. Failing to identify these hidden factors, one might treat it as a kind of error in measurement, simply ignoring these distribution tails. In contrast, we suggest that a true homogeneous multi-humped distribution may exist under far from equilibrium conditions. For example, the learning process cannot be a solely deterministic. Chance plays an important role in human development.

However, to prove the stochastic mechanism is not an easy task. In experiments, we need a large sample in a cross-age survey or a trace of a homogeneous group for a long time. In theory, the definition and measurement of development degree may be questionable for many models in social sciences. Without a sufficient number of states, an averaging procedure could easily hide a multi-humped distribution. Homogeneity is also a controversial concept, because it is difficult to exclude any hidden variables.

In spite of this, some social scientist data still encourages us to search the evidence of multi-humped distributions. One possible example is shown in Figure 8.2. A survey in the US examined the sexual maturation of boys and girls.

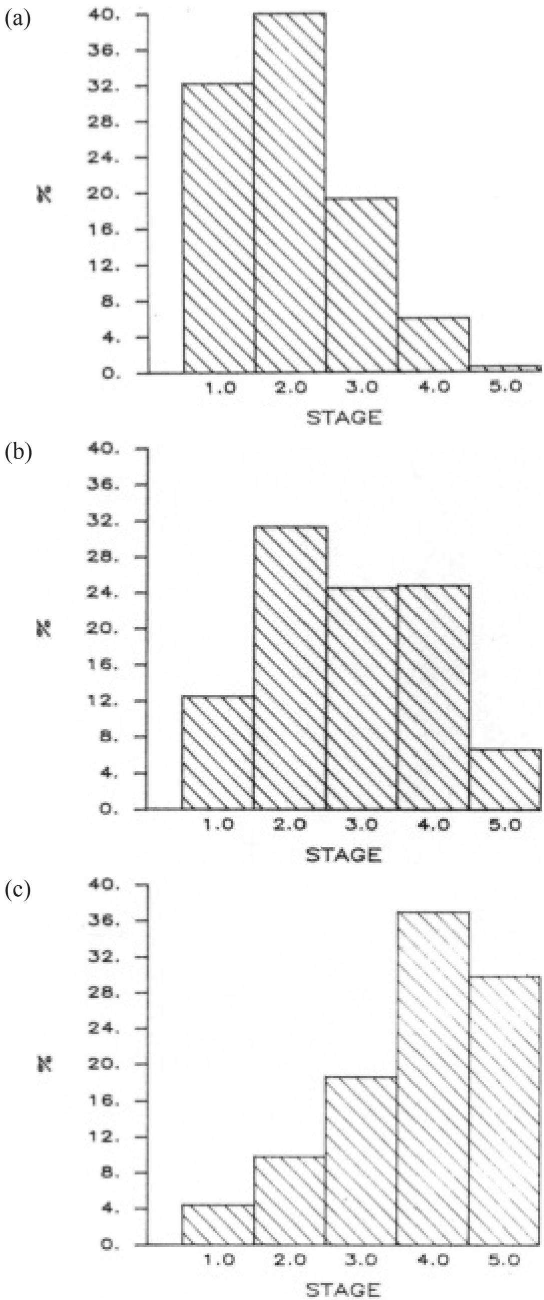


Figure 8.2 US survey of sexual maturation of white boys. (a) Age 12 (N = 540). (b) Age 13 (N = 538). (c) Age 14 (N = 525).

Note
The abscissa is the genital stage. N is the sample size.

A broad distribution in white girls of age 12 and a slightly dip in distribution for white boys of age 13 was discovered (Harlan *et al.* 1979, 1980). At least, there is some evidence of large fluctuations during this transition period. The breakdown of Gaussian distribution is a clear sign of nonequilibrium state. Further study in multi-staged process is worthwhile.

8.3.2 The bifurcation at the last meal

One may raise the question of the existence of bifurcations in social phenomena (Gould 1987). Because social scientists cannot do experiments, it seems impossible to observe bifurcation in social history.

To answer this question, let us consider an ideal case. Suppose a castle is encircled by overwhelming hostile forces. The castle is hard to attack both from land and sea. The best choice for the people in the castle is to stay inside as long as their food store lasts. But at the last meal, chaos spreads among the people. They face three choices. The old strategy to stay in the castle becomes unwise, since it only leads to die of hunger. And the survival chance to escape through a secret channel by land or sea seems the same. Some people prefer one way and some prefer the other. Obviously, there is a bifurcation point in decision making. The bifurcation parameter is the food stock. Bifurcation point is reached when food stock is zero. The state space is discrete. This scenario is familiar in history. Deterministic bifurcation theory is the average description of this sort of the event.

Although the above case is a thought experiment, we can easily see the point that the concepts of bifurcation and multi-humped distribution are relevant to understand social phenomena.

8.4 Concluding remarks

From the above simple models, we see how the stochastic mechanism plays an important role in social evolution. Developments in nonequilibrium physics and

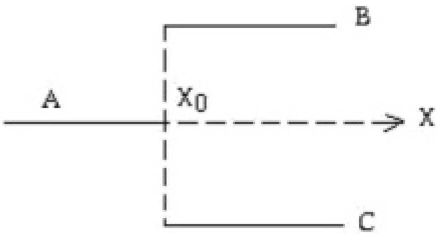


Figure 8.3 Bifurcation diagram of defense strategy in an island castle.

Notes
The stock of food is the bifurcation parameter X. X_0 is the bifurcation point when food stock is zero. Three strategic choices: state A, stay in the castle; state B, escape by land; state C, escape by sea.

chemistry not only provide useful tools for social sciences, but also change our concepts or paradigm in social theory. The nonequilibrium paradigm has developing a broader perspective than equilibrium paradigm in understanding a changing world.

Acknowledgments

I wish to thank Dr. J.L. Deneubourg for his intuitive idea of complementarities in social phenomena. I thank Prof. Ilya Prigogine and Dr. Weimou Zheng for their advice on multi-humped distribution. I also thank Prof. R.M. Malina. He introduces the empirical evidence of non-Gaussian distribution from adolescence survey.

9 Imitation, learning, and communication

Central or polarized patterns in collective actions[1]

9.1 Introduction

Neo-classical models in microeconomics often describe an atomized society, in which every individual makes his or her own decision based on individual independent preference without the communication and interaction with the fellow members within the same community (Varian 1984). Therefore, static economic theory cannot explain collective behavior and changes of social trends, such as fashion, popular name brand, political middling, or polarization.

Physicists have been interested in collective phenomena caused by the success of ferromagnetic theory in explaining collective phenomena under thermodynamic equilibrium. The Ising fish model (Callen and Shapero 1974) and the public opinion model (Weidlich 1972) represented the early efforts in developing complex dynamic theory of collective behavior. However, the human society is an open system. There is no ground to apply the technique of equilibrium statistical mechanics, especially the Maxwell-type transition probability, to social behavior. Therefore, these pioneer models have been discussed in the physics community, but received little attention among social scientists.

The development of nonequilibrium thermodynamics and theory of dissipative structure opened a new way to deal with complex dynamics in chemical systems and biological systems (Nicolis and Prigogine 1977, 1989; Haken 1977), which have potential applications in social behavior. In this short chapter, we will introduce a new type of transition probability into master equation from the perspective of socio-psychological mechanism. This model may shed light on collective behavior such as fashion, public choice, political campaign, and herd behavior in the financial market.

9.2 Stochastic models for imitation and collective behavior

Stochastic models are very useful in describing social processes (Callen and Shapero 1974; Weildlich 1972; Nicolis and Prigogine 1977; Haken 1977; Reichl 1980). To define basic concepts, we may start from the master equation and follow Haken's (1977) formulation of the public opinion model.

Let us consider a simplified situation that only two states of opinions, such as expectations of a bull or bear market or liberal or conservative agenda, are subject to public choice. The two opinions are denoted by the symbols of plus and minus. The formation of an individual's opinion is influenced by the presence of the fellow community members with the same or the opposite opinion. We may use a transition probability to describe the changes of opinions.

We denote the transition probabilities by

$$p_{+-}(n_+, n_-) \text{ and } p_{-+}(n_+, n_-)$$

where n_+ and n_- are the numbers of individuals holding the corresponding opinions + and –, respectively; p_{+-} denotes the opinion changes from state + to –, and p_{-+} denotes the opposite changes from – to +. We also denote the probability distribution function by $f(n_+, n_-; t)$. The master equation can be derived as follows:

$$\begin{aligned}\frac{df(n_+, n_-;t)}{dt} = &(n_+ + 1)\, p_{+-}(n_+ + 1, n_- - 1)\, f(n_+ + 1, n_- - 1; t) + \\ &(n_- + 1)\, p_{-+}(n_+ - 1, n_- + 1)\, f(n_+ - 1, n_- + 1; t) - \\ &[(n_+)\, p_{+-}(n_+, n_-) + (n_-)\, p_{-+}(n_+, n_-)]\, f(n_+, n_-; t)\end{aligned} \quad (9.1)$$

We may simplify the equation by introducing new variables and parameters:

Total population: $n = n_+ + n_-$

Order parameter: $q = \dfrac{n_+ - n_-}{2n}$

So we have:

$$n_+ = n\left(\frac{1}{2} + q\right)$$

$$n_- = n\left(\frac{1}{2} - q\right)$$

$$w_{+-}(q) = n_+ p_{+-}(n_+, n_-) = n\left(\frac{1}{2} + q\right) p_{+-}(q)$$

$$w_{-+}(q) = n_- p_{-+}(n_+, n_-) = n\left(\frac{1}{2} - q\right) p_{-+}(q)$$

where, n is the total number of the community members, q measures the difference ratio and can be regarded as an order parameter, $w_{+-}(q)$ and $w_{-+}(q)$ are the new function describing the opinion change rate which is a function of order parameter q.

This equation can describe collective behavior such as formation of public opinion, imitation, fashion, and mass movement following a crowd. The problem is still unsolved about the transition probabilities $p_{+-}(n_+, n_-)$ and $p_{-+}(n_+, n_-)$. The form of transition probability is closely associated with the assumption of communication patterns in human behavior.

9.3 Ising model of collective behavior

The early attempt to formulate collective behavior was directly borrowed from the transition probability of the Ising model in equilibrium phase transition (Callen and Shapero 1974; Weildlich 1972; Haken 1977). The phase transition from paramagnetic state to a ferromagnetic state on a magnetic lattice in equilibrium statistic mechanics is used as a formulation of sudden changes in fashion or market sentimental (Reichl 1980). Haken defined the transition probability in analog of the Ising model:

$$p_{+-}(q) = p_{+-}(n_+, n_-) = v\exp\left(-\frac{Iq+H}{Q}\right) = u\exp[-(q\theta+h)]$$

$$p_{-+}(q) = p_{-+}(n_+, n_-) = v\exp\left(+\frac{Iq+H}{Q}\right) = u\exp[+(q\theta+h)]$$

$$\text{with } \theta = \frac{I}{Q} \text{ and } h = \frac{H}{Q}$$

where, u is the frequency of flipping process, I is a measure of the strength of adaptation to neighbors or interaction constant, and θ is normalized interaction. One could realize that the mutual interaction is low in an individual culture but high in a collective society.

H is intensity of social field such as the influence of mass media or social trend ($H > 0$ means that opinion + is preferred to –). We may label liberal trend as +, and conservative trend as –. The corresponding variable in physics is the magnetic field. The means of social field include commercial advertising, political campaign, and propaganda.

Q is a measure of warmness in social temperature, while θ is a measure of coolness in collective atmosphere. The parallel concept is heat energy kT in statistical physics. Here k is the Boltzmann constant and T is the absolute temperature. The social climate is warm (indicated by high Q) or collective atmosphere is cool (indicated by low θ, when political tension is low and social tolerance is wide for diversified public opinion. A physics perspective is that individual culture is characterized by random movement in high temperature while collective behavior looks like magnetic resonance under low temperature. Heating influence is balanced by magnetic field in shaping molecule movement under thermal environment.

For mathematical simplicity, we assume away media influence, that is the cases of $h = 0$. The unimodal distribution with peak in the center provides a stylized picture when social opinion is dominated by no visible trend. Master equation (9.1) can be transformed into a partial differential equation, which has two kinds of steady-state solutions (see Figure 9.1). The analytic solution of steady state is given by:

$$Fst(q) = c\exp\left[2\frac{K_1(y)}{K_2(Y)}dy\right] / K_2(q)$$

1 The first type of steady solution is the central distribution when frequent changes of opinion occur. It happens under high social temperature and weak interpersonal interaction. The case (Figure 9.1a) (with k = 0) may imply an atomized society without any social interaction, which is a statistical model of Robinson Crusoe economy.

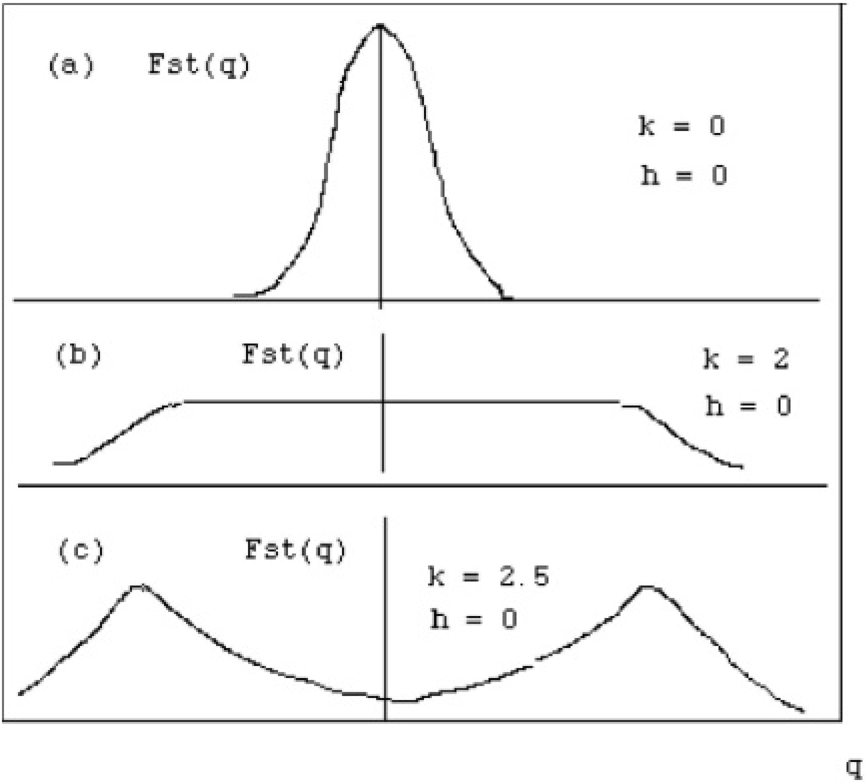


Figure 9.1 The steady state of probability distribution function in the Ising model of collective behavior without media effect (h = 0). (a) Central distribution with k = 0. Moderate behavior under high social temperature and weak interaction in societies. (b) Marginal distribution at the phase transition with k = 2. Behavioral phase transition occurs between moderation and polarization in collective behavior. (c) Bi-modular or polarized distribution with k = 2.5. Strongly correlated behavior is shaped by low social temperature and strong mutual interactions.

2 The second type of steady solution is a bi-modular distribution. Polarization in public opinions is shaped by strong neighbor interaction under low social temperature and high collective atmosphere, which is illustrated in the case (Figure 9.1c) (with $k > 2.5$ and $h = 0$).

3 If we consider the influence of mass media or advertising, then we have a social magnetic field H. When social field $H > 0$, or $H < 0$, the peak distribution may shift to right or left, by strong mass media or social trend.

The Ising model of collective behavior gives some qualitative pictures of collective phenomena. However, the Ising model has some problems with social phenomena. First, society is not a closed system. Theoretically speaking, the equilibrium thermodynamics and statistical mechanics cannot be applied to social systems. Second, the transition probability of the Ising model has no theoretical foundation in human systems. Social temperature Q and social field H have no measurable definition. Therefore, they are not observational indicators.

To overcome the difficulties of the Ising model, we may shift transition probability from equilibrium statistical mechanics to population dynamics in order to formulate the transition probability functions.

9.4 Socio-psychological model of collective choice

Consider a socio-psychological process with simple interaction relation (Chen 1987a).

$$w(n_+, n_-) = a_1 n_+ + b_1 n_+ n_- \tag{9.2a}$$

$$w(n_-, n_+) = a_2 n_- + b_2 n_+ n_- \tag{9.2b}$$

This transition probability has a simple explanation: the rates of changes in personal opinion depend both on the population size holding the same opinion (as shown in the first term in the right-hand side of equation) and the interaction through communication between individuals holding opposite opinions. The balance between independent choice and social pressure is determined by the relative strength of communication and interaction, say, the enhancing effect of a by population size with the same opinion and the switching effect of b by population size with opposing opinion. Here, we set $a_1 = a_2 = a$ and $b_1 = b_2 = b$ for simplicity.

Using new transition probability (9.2), we may solve the master equation (9.1) with two new forms of steady state solutions (see Figure 9.2) (Bartholomew 1982; Mansour and de Palma 1983).

1 When $b < a$, we have central distribution without polarization. A moderate society implies that independent decision overcomes the influence of social pressure in social systems. When the middle class plays a dominating role, an open attitude may prevail in individualistic and pluralistic societies.

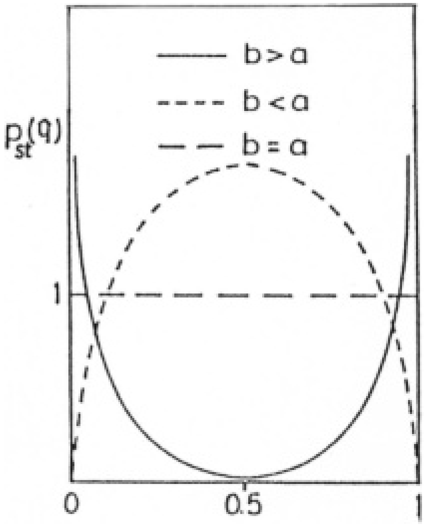


Figure 9.2 The steady state of probability distribution function in socio-psychological model of collective choice.

Notes
Centered distribution with b < a (denoted by short dashed curve). It happens when independent decision rooted in individualistic orientation overcomes social pressure through mutual communication.

2 When b > a, we have U-shaped distribution. It means that personal decision is heavily influenced by social opinion. This situation is often observed in religious war and polarized revolution or mass movements, when societies are polarized by racial, cultural, economic, and political polarization. Great uncertainty under the U-shaped distribution provides a statistical description of animal behavior or irrational fads, which is observable in the financial market.

From the above model and observation, we may reach a surprising conclusion that modern communication may actually enlarge collective behavior and market uncertainty. The classical model of rational behavior and individualistic culture is more relevant to pre-modern society with poor transportation and communication among individuals. To reduce social polarization, competition policy in mass media and macro management of social fads are useful in dealing with financial crisis.

9.5 Potential applications of collective choice

In this short chapter, we developed the stochastic approach in addressing the collective behavior in human society. The equilibrium Ising model is replaced by interactive population model with check and balance between individualistic orientation and social pressure through neighbor communication.

We may also apply the deterministic approach of competition model in theoretical biology (Chen 1987a, b). The role of learning in addition to communication may have fundamental impact in studying social behavior.

There are many problems that are interesting for further research:

- *Theoretical biology:* learning behavior in prey-predator and competition models.
- *Sociology:* information diffusion, fashion, and immigration.
- *Political Science:* conflicting interest groups, arms race, voting, political campaign, social trend, and differentiation.
- *Economy:* staged economic growth, fashion switching, risk-taking and risk-aversion strategies in investment, marketing, merger and acquisition.

9.6 Conclusion

Nonequilibrium physics and population dynamics open a new way to understand social phenomena. Stochastic model with nonlinear transition probability is capable to describe the collective choice and social fashions. Great uncertainty or animal spirits occurs under polarized distribution with intensive social interactions (Keynes 1936).

10 Needham's question and China's evolution

Cases of nonequilibrium social transition[1]

10.1 Introduction: Needham's question and Prigogine's theory

The history of Chinese civilization has many distinctive characteristics: the gigantic bureaucratic system of the long-lasting centralized Chinese Empire, its hostile policy toward the merchant class, and its cyclic dynasties and peasant rebellion. These characteristics are in sharp contrast to Western civilization with the fragmented feudal society, powerful Christian church, and autonomous cities. Chinese history could serve as a counter-example of the Western mode of historical evolution and as a touchstone for competing models in social sciences and philosophy of history.

During China's Cultural Revolution in the late 1960s and 1970s, I became interested in Needham's (1954) question: why did science and capitalism emerge in Western Europe but not in Chinese, Indian, Islamic, or other civilizations? A parallel question: what are the sources of the stability and longevity of the centralized Chinese bureaucracy which has survived for more than 2000 years and continues to be a major obstacle to the development of a market economy and a modern society (Elvin 1973)?

The attempt to answer Needham's question brought me to an unanticipated application of Ilya Prigogine's nonequilibrium thermodynamics to social phenomena when I read Prigogine's paper on the thermodynamics of evolution in the spring of 1973 (Prigogine *et al.* 1972). Prigogine classified thermodynamic systems into three categories: isolated systems, closed systems, and open systems. Nonequilibrium thermodynamics simply asserted that self-organization emerged only in open systems. It occurred to me that the degree of openness and adaptability to changing environment was the key to comprehending the diversity of civilizations in history (Chen 1979, 1988a).

A related perplexity is the relationship between stability and complexity. Chinese society was characterized by its self-sufficient economy and labor-intensive agriculture. Compared with the Western pluralistic society with its open economy and highly developed division of labor, traditional Chinese society was a rather simplistic, monolithic society with remarkable structural stability which had endured cyclic turbulence over time. As expected in theoretical biology, complexity seems to be related to stability according to the Darwinian doctrine: the fittest survives. However, both mathematical modeling and historical observation led me to an opposite conclusion – that complexity implied instability rather than stability (Chen 1987a). From the viewpoint of nonequilibrium and nonlinear physics, instability not only implies the possibility of destroying an old order but also the opportunity of creating new structures. In this chapter, I will address historical and theoretical issues first, and then discuss problems in China's reform and recent crisis.

10.2 Openness of the economy and the stability of agriculture

Needham's question, asking why science and capitalism emerged in Western Europe but not in China, has puzzled many historians (Needham 1954; Wittfogel 1957; Wallerstein 1974; Braudel 1981; Jin and Liu 1984; Huang 1985).

Marxist-Maoist historians laid the blame for the stalemate of Chinese society on the brutal exploitation of the peasants by the Chinese ruling landlord class. But a quantitative investigation of land taxes in the sixteenth century revealed that China's land tax rate was generally in a range of 1 percent to 10 percent which was much lower than taxes in medieval England and Japan (Huang 1974). Rather it was institutional incapability that was responsible for China's backwardness (Needham and Huang 1974). Weber emphasized the significance of culture (1964). In his opinion, the development of capitalism in the West was driven by the Protestant zeal for accumulation of capital while China was at a standstill due to the Confucian tradition. So, we should ask what the sources of conservative culture and institutions were.

Elvin interpreted the stagnation of the Chinese economy after the Song dynasty (AD 960–1279) as a high level equilibrium trap in development (1973), since there was only quantitative growth, but qualitative still with no fundamental change in technology. So the question became why did a technological revolution not emerge to spring the trap in China? Perkins pointed out the importance of demographic factors in economic growth (1969). He found that the growth rate of agricultural production was lower than the growth rate of population in the last four centuries. However, it was difficult to determine whether the population factor played a positive or negative role in economic development. Boserup argued that a certain amount of population pressure was necessary to adopt new technology (1965).

Although many factors might contribute to the emergence of capitalism and modern science in the West, openness of economy and society was a necessary condition for developing capitalism and modern technology (Chen 1979, 1988a). According to Prigogine, the destruction of order and increase of entropy always occur in isolated systems; a static structure like a crystal may form in closed systems; self-organization and structural evolution can only develop in open systems where energy flow, matter flow, and information (entropy) flow exist. Nonlinearity and instability (positive feedback) play critical roles in forming dissipative structures (Prigogine *et al.* 1972; Nicolis and Prigogine 1977). Prigogine's idea sheds the light on social transition.

There was an astonishing contrast between the openness of the Western economy and the near-closeness of Chinese society. Encouraging foreign trade and encouraging city business was the traditional policy of European countries in the middle ages. But the Chinese government had tight control of city commerce since the eighth century BC. China had carried out a closed-door policy in the Ming and Qing dynasties (AD fourteenth and nineteenth centuries) until Western gunboats opened the closed door of China. Even the patterns of war in the West and the East were different. Europeans often fought to control vital trade routes, while the Chinese struggled to acquire arable land. Chaunu once observed a paradoxical phenomenon in history that could not be explained by the theories of Malthus or Weber: "The European wastes space. Even at the demographic low point of the beginning of the 15th century, Europe lacked space.... But if Europe lacks space, China lacks men" (Wallerstein 1974).

We will call this observation the Chaunu–Wallerstein puzzle, which is closely related to Needham's question. Then the question was why did China keep a closed-door policy under the pressure of increasing population while Western countries had being seeking to expand territorially under the banner of an open-door policy since the fifteenth century? We should identify the deep structure that shaped the different civilizations in Europe and China (Chen 1979, 1988a).

Braudel developed a three-level model of human civilizations: the material life, the market economy, and the world system (1981). We have generalized his model into a pyramid of human society (see Figure 10.1). In the bottom level, material life includes environment (geography, climate, and resources), population, and resource. Traditionally, the study of political economy is only concerned with the middle level of market economy. A more general view should

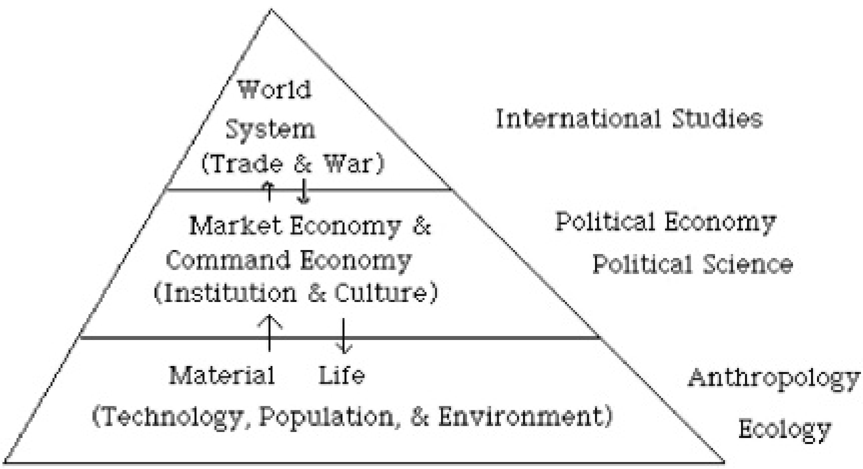


Figure 10.1 The structural pyramid of human society.

also consider the subsistence economy as well (Huang 1985). Braudel strongly argued that material civilization determined the basic structure of economy. Anthropologists emphasized that environment played a fundamental role in shaping the culture and social institution (Harris 1974, 1980). We found out that the lower level may have a fundamental impact to the levels above, but the interplay among the three levels is also important in history, since development is a dynamic and irreversible process.

The dissimilarity in environments is associated with significant differences in economic structure and political behavior. Western civilization arose around the Mediterranean Sea, which serves as the main trade route between the East and the West. China is basically an inland country, and most areas are not accessible to the sea. More than 50 percent of the Europe continent is plains while 90 percent of China proper is mountainous. Developing transportation and division of labor was, therefore, much easier for the Europeans than for the Chinese. Lacking development of transportation and division of labor has been a key factor to foster a self-sufficient economy in China since its early stages.

Environment was a strong factor in determining the pattern of agriculture, which in turn shaped the original institutions and culture of civilizations. European agriculture consists of mixed crops and livestock farming (Rubenstein and Bacon 1983). Dairy products and meat are the main staples in the Western food structure. However, Chinese agriculture consists of a simple structure of intensive farming since grain and vegetables are the main foods for the majority of Chinese people. Dairy products had no role in Han majority people. Pork, rather than beef, served as the main source of meat. European farms were generally 100 times larger than Chinese farms in the Middle Ages. In contrast, China's war scale was ten times larger than Western Europe's. Historically, China had 13 times of peasant wars and foreign invasion that wiped out about half the population in 2000 years of cyclic dynasty (Chen 1979). Europe had only once that population dropped more than one-third, the Black Death in the Middle Ages. We should bear in mind that China and Western Europe had similar size of land and population.

Presumably, the principal motivation for European expansion in the sixteenth century was the need for land rather than the call of religion. The Black Death may also have stimulated the development of labor-saving technology in Europe. Nevertheless, the land-conserving intensive farming developed in China only led to population crises and cyclic peasant wars. Similarly, socialism may have emerged in Eastern Europe and China, because the inland countries had disadvantage in competing with the coastal areas. The modern market economy first prospered in island countries and coastal areas such as Italy, the Netherlands, and England in the West, and Japan in the East because their transportation costs were low.

The resource efficiency of labor-intensive agriculture and the labor efficiency of capital-intensive technology characterize the Chinese and Western civilizations respectively. They are complementary ways of adapting to the natural environment. Economists often speak about the efficiency of allocating resources in market economy without specifying the higher resource cost of industrialization. The efficiency of energy use in traditional societies was actually higher than it is in modern societies because the food web of the former is much simpler than the latter. As Chaunu put it: "The emphasis on cattle in Europe led to the extensive use of animal muscular power as an engine of production. Rice is far more fruitful in calories per acre but far more demanding of manpower" (Wallerstein 1974).

One interesting aspect is the importance of the spice trade in the Western economy. Europeans needed spice, which was imported from Indonesia and India, to preserve meat. Therefore certain oriental products like spice become basic goods in Western material life (Thompson 1928). Europeans went west seeking new routes to India because the Turks had blocked the traditional trade route through mid-Asia and Arabia in the mid-fifteenth century. The economic need to import crucial products and political pressure to protect vital trade routes became constant motives for open-door diplomacy and colonial policy in Western history. The Chinese never felt the critical need for foreign trade as a material necessity. The bulk of Chinese foreign trade imported luxury goods for the upper class. The primary concern of Chinese rulers was national security – defense of the country from the menace of nomads in the northwest and pirates from the sea. This orientation was responsible in the past for closed-door diplomacy and the self-sufficient policy.

Geographic determinism, cultural determinism, and economic determinism are typical examples of linear (uni-causal) thinking. To address Needham's question from a nonlinear dynamical perspective, we may integrate the multi-layer multi-dimensional analysis into a united theory of dissipative structure. Different civilizations in East and West are deeply rooted in interactions between external environment and internal structure. These dimensions include geography, climate, demography, technology, economy, culture, and social institution. No single variable can determine the multi-fold evolutionary course. And social evolution is not an "inevitable" or predictable deterministic process. The emergence of capitalism and science must be rare events in history whose survival probability could be as small as those of life at the dawn of history.

10.3 Historical bifurcations caused by fluctuations in the environment

In analyzing the adaptability of technology and the degree of cultural rigidity in social evolution, the pattern of agriculture emerges as crucial in shaping cultures and institutions. The pastoral nomadism in the Middle East and Central Asia is an unstable form of agriculture, while intensive farming in China and India is a very stable one. The mixed crop and livestock farming in Europe is a flexible and adaptive structure with metastable stability (Chen 1979, 1988a; Rubenstein and Bacon 1983).

The difference in the food structures of the East and West may resolve one paradox in history. Although the populations of the two empires were roughly of the same magnitudes, there were far fewer Roman soldiers than soldiers in the Chinese Han Europe. The scale of Chinese peasant wars in the Middle Ages was comparable to those of world wars in industrialized society. The technical possibility of storing grain from intensive agriculture made possible the logistic support possible to maintain a standing army of many millions of soldiers in China, while the Roman army had difficulty storing enough meat and dairy food for even hundreds of thousands of men in a mixed agriculture (Chen 1979, 1988a). Grain production and storage were the very foundation of China's unity, which was achieved by means of military control and bureaucratic centralization (Chi 1936). In this regard, we could say intensive farming together with hydraulic engineering was a technology that supported centralization while mixed farming with natural irrigation was a technology that led to division of labor. The characteristics of the dominating technology shaped the orientation of institutions and culture.

According to Schrödinger, it is the metastable state or aperiodic solid that may be the very foundation of living structures (1944). From the view of non-equilibrium physics, aperiodic solids and metastable states must exist in a non-linear open system. An analog between dynamical stability and social structure is shown in Figure 10.2. Only systems with the proper degree of openness and appropriate stability have the chance to evolve to the complex form and advanced stage of life and civilization.

The historic course of social evolution is neither purely deterministic nor totally random. The development of China's intensive farming is a typical case of order through fluctuations in history. Until the Shang dynasty (sixteenth to eleventh centuries BC), archaeological records show that Chinese agriculture was mixed agriculture with a large share of animal husbandry. The dramatic social transition of the Spring and Autumn period (770–476 BC) occurred at almost the same time Greek civilization was flourishing. The population grew rapidly and land became a scarce resource. The manor system based on extensive farming collapsed and the landlord system based on intensive farming emerged during this period. This period also marked the very beginning of the chronic dynastic cycles, which brought more than 2000 years of civil wars and peasant rebellions. Chinese Marxist historians regard the Spring and Autumn period as a revolution

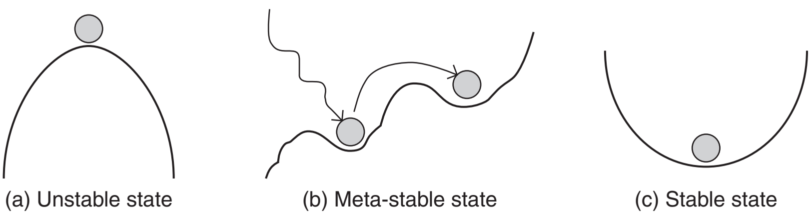


Figure 10.2 System stability under external shocks. (a) Unstable state. (b) Metastable state. (c) Stable state.

in a slave society that resulted in a feudal society according to Stalin's five-stage scenario (Mao 1967). So-called historical materialism asserts that historical development should follow a deterministic sequence – such as primitive communal, slave, feudal, capitalist, and then socialist society (Stalin 1940). But the Needham question makes it difficult for the Marxist historians to explain the Chinese history.

We submit that the dissimilarity between Chinese and Western civilizations is simply due to a bifurcation in agriculture caused by climate fluctuation. According to the meteorologist Zhu, China had a subtropical climate during the Yin dynasty (fourteenth to eleventh centuries BC). The climate became very cold in the Zhou dynasty (eleventh to eighth centuries BC) and warm again in the Spring and Autumn period (eighth to fifth centuries BC) (Zhu 1979). A possible scenario of social evolution in China between the fourteenth and the fifth centuries BC is this: mixed crops and livestock farming was prevalent in the warm period of Yin. Animal husbandry was almost destroyed by cold weather in Zhou, and only such cold-resistant crops as wheat and millet survived the cold wave. When climate became warm again, the yields of crops increased and population grew. However, the northeastern plains of China were not large enough to support a dense population with mixed crops and livestock. So the transition from extensive farming and mixed agriculture to intensive farming to produce more grain to support an ever denser population became an irreversible trend in Chinese history.

Another event in 1453 caused a second major bifurcation in world history: Constantinople fell to the Turks and the eastern Mediterranean was closed to Western Europe. European sailors were forced to search for a new route from West to East. This effort led to the discovery of the New World and the development of a world market that made way for industrial revolution and capitalism (Cooper 1985).

The bifurcated tree of world civilization is illustrated in Figure 10.3. Here we see again interactions among the deterministic mechanism of natural environment and social structure and the stochastic "events" in changing climate, technology, and political landscape.

10.4 The Darwin dilemma concerning complexity and stability and cultural factors in learning and competition

A question related to Needham's problem is its unusual stability and longevity of the centralized Chinese Empire, which survived for more than 2100 years. Even the present People's Republic has inherited many imperial traditions from the past. In Western history, the Byzantine Empire lasted about 1100 years (from AD 330 to AD 1453), and the Roman Empire existed for only 500 years (from 27 BC to AD 476). Other Western empires in pre-modern history collapsed even faster than the Romans. Decentralization and cultural diversity are the main features of European civilization. In contrast, China has been a united country under a centralized bureaucratic government since 221 BC. The origin of the state and

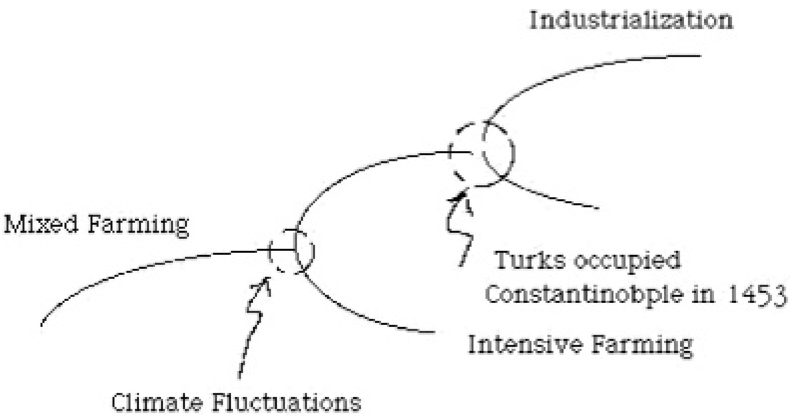


Figure 10.3 The bifurcation tree of civilizations in history.

the mechanism of stability has been a puzzle in the political sciences. In the previous section, we addressed the issue from the technical characteristics of the agricultural structure. Now we will discuss the origin of division of labor by analyzing community complexity.

A parallel dilemma was recognized in theoretical ecology regarding the relationship between stability and complexity. There was a belief among biologists that increased web complexity would cause increased stability when studying the evolution of species communities. However, mathematical simulations have shown an opposite conclusion (Gardner and Ashby 1970; May 1974a). For instance, the stability of a two-co-existent-species system is less stable than a single one. Many theoretical biologists doubted the models were realistic enough to reflect the nature of living systems. We believe that May's discovery was fundamentally correct because the reverse correlation between stability and complexity could be justified from experience in human history. For example, a Chinese village with its simpler structure would recover much more easily from a power failure or military attack than New York city would.

It is realized that culture plays an important role in the origin of capitalism and sciences (Weber 1930). Kikuchi is aware of differences in the degree of "individualism" existing in the Eastern and Western nations (1981). We extended population competition model with a cultural factor, which has been emphasized by psychologists but overlooked by economists (Chen 1987a; Hogarth and Reder 1987).

Some economists and evolutionary biologists justify their optimization theory of living behavior by assuming the selfish nature of human being or even the gene (Dawkins 1976). However, empirical investigation cannot determine whether a living being is selfish or altruistic. We suggest a socio-psychological indicator to measure collectivistic, or risk-averse, behavior and individualistic, or adventure-loving, behavior; these are characteristics that can be observed (see

Figure 10.4). Varying this behavioral parameter, we may have a wide spectrum of degrees of "individualism" in diversified behaviors or cultures, from solitary to social animals, or from progressive to conservative cultures. Then we can introduce the cultural behavioral factor into the information-diffusion process and the learning competition model. Different cultural orientation in exploring new resources or technology leads to new understanding of the origin of division of labor and differentiation of society (Chen 1987a).

It is shown in the model that a progressive species needs a larger subsistence space than a conservative one in order to maintain the same population size. This is why some aggressive species with low population density need larger subsistence space. In section 10.2, the Chaunu–Wallerstein puzzle was explained by difference in agriculture structure. We will further examine the issue from cultural behavior in learning competition. Historically, Western ranchers and merchants were more adventurous than Chinese peasants and bureaucrats.

Another interesting result is the stability of culture in a fluctuating environment. It has been found that a conservative culture is more stable than a progressive one. This is especially true when some survival threshold population size obtains and resources are limited. But when new information comes,

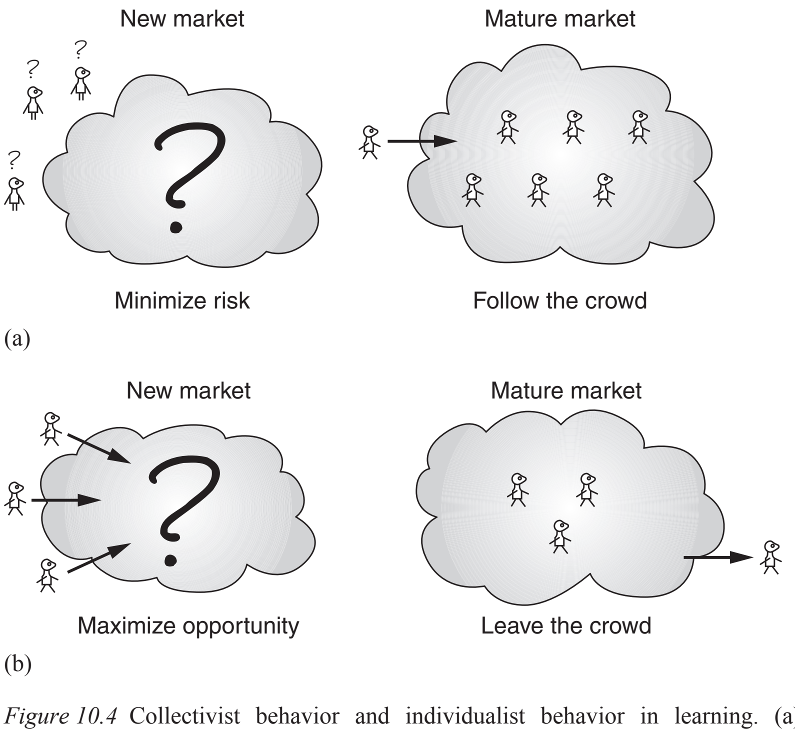


Figure 10.4 Collectivist behavior and individualist behavior in learning. (a) Risk-aversion behavior of collectivists: the conservative strategy for minimizing uncertainty, which is often observed in collective culture. (b) Risk-taking behavior of individualists: the contrarian strategy for maximizing opportunity, which is often observed in individualist culture.

a conservative species is less inclined to absorb new technology than in a progressive species.

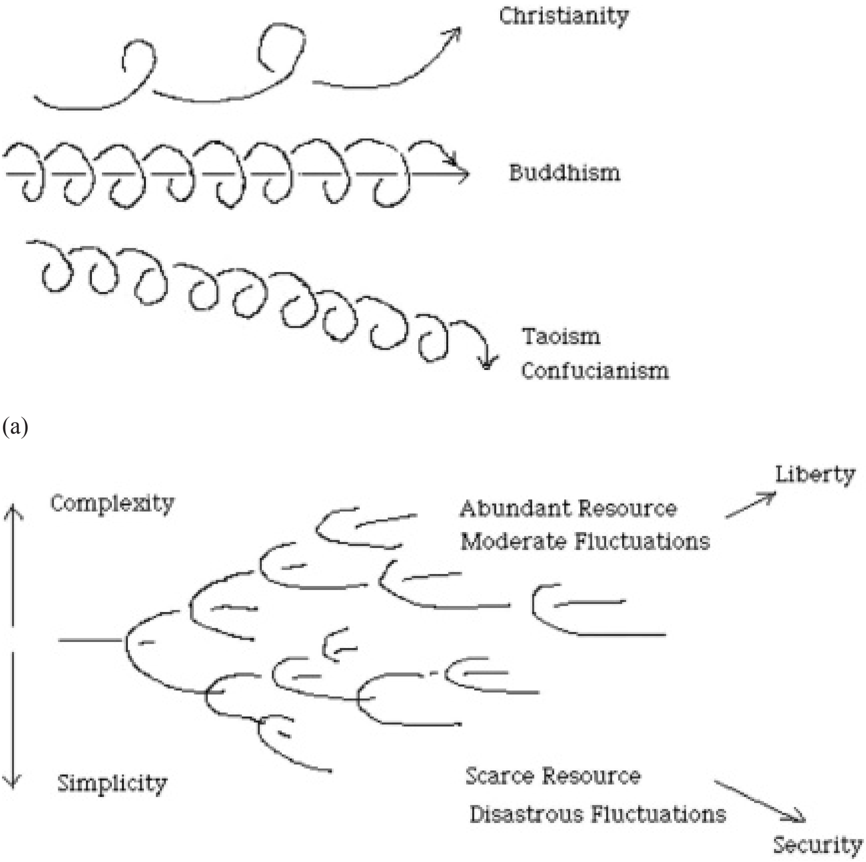
The most interesting investigation is of the competitiveness between two species with different learning behavior in exploring new resources. It has been shown that two conservative species cannot co-exist, but two progressive species can. When they compete for the same resource or same idea, such as arable land or a dominating ideology, the only possible result is that one replaces the other. It is the story of cyclic dynasties in history, which repeatedly occurred in traditional monolithic societies such as those in Oriental countries. Therefore division of labor cannot emerge in a conservative culture.

If two species have equal learning ability, progressive species may have difficulty in competing with conservative species. The survival strategy for progressive species is constantly improving their learning ability. If we consider capitalism as an adventure-loving culture, then we may reach a conclusion similar to Schumpeter's – that innovation is vital for capitalism when competing with socialism (Schumpeter 1950). Once innovations cease, capitalism will lose in the competition for existing resources. If their learning abilities are not equal, there is variety of possibilities for competing species, so we could have a diversified world. Another interesting result of the model is that a mixed society of conservative and progressive species is more stable than a mixture of two progressive species. This phenomenon is observable from Anglo-Saxon political systems.

Studying the stability against a fluctuating environment reveals that a monolithic society is more stable than a pluralistic one, although a pluralistic society enjoys more social wealth than does a monolithic society. There is a trade-off between stability and complexity, or, security and development, which sheds some light on the differences between Occidental and Oriental cultures. Theoretically speaking, division of labor certainly has its benefits and costs. The cost of industrialization is a greater risk of instability. That is the price we have paid for modernization.

The "time arrow in history" has been perceived in different ways in different civilizations. Indian Buddhism had a cyclic view of history. Judaism and Christians believed in a better life in the future, while Confucius and Taoism believed the past life was better. The Chinese orientation toward conservative culture can be understood by considering the deteriorating environment of intensive farming. Based on this discussion, we may discuss the evolutionary tree of social history (Figure 10.5). Clearly, it consists of a two-way development that has been moving toward simplicity or complexity, depending on the environment and the structure of the system. Development is a multi-linear process toward a diversified world, not a fated convergence toward communism or capitalism. There is no theoretical foundation for the convergent view in world history. Nonlinear dynamics and evolutionary thermodynamics have a different perspective from neo-classical economics based on methodological individualism.

We might speculate about why capitalism emerged in the West and not in the East. Disasters and wars happened much frequently in China than in Europe and



(a)

(b)

Figure 10.5 The time arrow in history and the two-way development of evolutionary trends toward complexity and simplicity.

were much severe (Chen 1979). Environmental fluctuation in China is too large to maintain a complex structure in the past. We may reverse Mao's evaluation of the positive role of the Chinese peasant wars since the Chin dynasty in the second century BC. The transition from mixed agriculture to intensive farming, which was parallel to the transition from manor system to landlord system, was devolution from complexity to simplicity in a deteriorating ecological environment (Chen 1979, 1988a). Contrary to the Maoist hypothesis that China's "capitalist seeds" could develop into full-blown capitalism without Western influences, we concluded that China had little chance to rediscover science and capitalism without opening to the Western world. This is our starting point for observing China's recent reform in the last decade.

10.5 Some observations on China's reform and the Beijing crisis

China's reform raises serious challenges to mainstream economics. China is a vast country with great geographical, structural, and economic disequilibrium. Its evolution from a traditional society to an industrial society cannot be comprehended by both Marxist economics and neo-classical economics (Chen 1988b). However, the emergence of newly developed evolutionary dynamics and nonlinear economics sheds light on complex dynamics and structural changes that are critical issues in China as well as in the changing world economy.

In this brief discussion, I make some observations on China's economic and political reform. I expect stimulating responses from readers.

10.5.1 The origin of socialism and the cost of capitalism

Poor environment, difficult transportation, and scarce resources form the soil of self-sufficient agriculture in traditional China and of the rationing economy in communist China.

The present socialist system emerged in poor countries during two world wars. Socialism has demonstrated its resource-saving efficiency to achieve the national independence and military security at a cost of low living standard and low social mobility. The socialist system may not be a more advanced stage that follows industrial capitalism but a complementary way to achieve industrialization in inland areas or poor countries, because a centralized government can mobilize national resources to rapidly improve infrastructure and human resources at an early stage to develop capital-intensive industry. But a socialist economy has difficulty in developing new technology in the world market.

The capitalist system has proved its time-saving efficiency and greater material variety in mass consumption (Berger 1986) at a cost of high consumption of energy and natural resources. A successful market economy needs many basic conditions: an open world economy, accessible transportation, appropriate technology, a balanced education system, operational institutions, and strong leadership in management and administration. To establish or improve these necessary conditions for the market economy, it may take decades of persistent effort and reasonable policy. However, the necessary conditions cannot be achieved by overnight revolution. Nor will one-time surgery achieve so-called market equilibrium in a country that lacks the basic infrastructure and requisite institutions for a market economy.

A tenable reform in socialist countries must consist of a deliberate mixed economy that includes an open market for consumer goods, public sector in utility and strategic industry, and some rationing system for scarce basic goods. A naive program of wholesale westernization is doomed to fail.

10.5.2 Volatile interactions between the international environment and domestic balance

China has a long tradition of regionalism due to the great discrepancy between its natural endowment and economic development (Mao 1967). The commodity economy in the coastal provinces is more developed than it is in the inland area. In the past, the formidable fighting forces that were the military power of centralized China consisted of poor peasants from the harsh environment of the inland area; and the grain supply and government revenue came from the economically wealthy southeast (Chi 1936). The cyclic policy swing in modern Chinese history from closed-door to open-door policy, from pro-Russian to pro-Western diplomacy, from conservative to liberal government, and from rationing to the market economy are highly dependent on the power balance between political factions in the inland area and coastal provinces. Generally speaking, the international environment has tremendous impact on which group will have the upper hand in internal conflicts. Military hard-liners who represent the interests of the inland area often win the political struggle when a foreign menace becomes a major challenge to the nation or when the country is torn by protracted civil war. Mercantile moderates who embody the interests of coastal provinces may emerge as the dominating force during a peaceful time of international environment combined with domestic prosperity. Therefore, keeping China's door open is the critical prerequisite for the advancement of any kind of reform in China. It is naive to address China's affairs from a purely ideological or political standpoint; it will be helpful to analyze China's evolution in a multi-dimensional framework.

The twists and turns of political reform are heavily influenced by interactions with the international environment. China's economic reform gained the momentum from the thaw in the cold war. China's economic reform also put strong pressure on the Soviet ruling class to end their expansionist policy. However, the emergence of Polish solidarity and Hungarian opposition parties alarmed the aging Chinese hard-liners who feared the loss of socialist sovereignty. Detente in Sino-Soviet relations relieved Chinese leaders of the fear of Russian invasion, enabling them to withdraw troops from the Sino-Soviet border to reduce defensive burden for economic development. No one could have predicted the recent Beijing tragedy since instability and uncertainty always exist in open systems. However, I still believe that instability means not only negative risk but also positive opportunity.

10.5.3 The ecological and economic sources of cultural and political orientation

Socialist ideology is a product of the traditional values of a subsistence economy and the war-time experience of military discipline. The socialist demand for equality is rooted in subsistence economic conditions (Wang and Bai 1985). Only when the material life of the majority people is much improved, can the demand for liberty prevail over the demand for security. In other words, in a capitalist democracy equal opportunity is the demand of the middle class, while in a socialist democracy equal distribution is the cry of poor people. Thus the protest made by the Chinese students' pro-democracy movement against official corruption is more closely related to traditional egalitarianism and intellectual protest than to bourgeoisie liberalism. Even in Western societies, the new knowledge class is a major antagonist of capitalism (Berger 1986).

Western democracy, where the majority rules in a multi-party system, is more successful in countries with relatively homogeneous economies and cultures and less successful in extremely heterogeneous countries. A balanced demand for personal liberty and equality is essential to achieve a mixed economy and pluralistic politics. I do not believe the Chinese people could afford to adopt Western institutions in total because of their high communication and operation costs.

10.5.4 The predicament of rational sequence in China's reform: which should come first, economic reform or political reform?

More precisely, the question is whether the old bureaucracy that controls the command economy can be transformed into an institution that regulates the market economy. If yes, then, how? A related problem is what will give the bureaucrats an interest in carrying out the institutional reform?

History has witnessed the hardship of the so-called proletariat dictatorship both in Stalin's Russia and in Mao's China. But it may be wrong to compare the status of socialist bureaucrats with the privilege of feudal aristocrats. There is an inherent contradiction in socialist morality (Kornai 1980). Under the communist system, private property is a sin and its guardians should not be honored. Therefore, the economic interests and material benefits of the ruling class are not legally protected by institutions and are highly vulnerable to political challengers. This is why internal conflicts within the ruling party in socialist countries are much fiercer than those in capitalistic countries. Limited choices and scarce resources intensify the political struggle in socialist societies.

I doubt the present form of political centralization in socialist countries can last very long. During the peaceful international environment and stable economic growth, governing by ideology and seniority will be gradually replaced by governing by law and education. I think it will be much easier to resolve the political deadlock by economic and procedural means.

Providing economic incentives and educational opportunities should be a necessary condition for transforming traditional officials into business managers or public servants. Relaxing the goal of distribution equality in exchange for a greater degree of political freedom and economic opportunity is a deal worth serious experiment in the reform of China.

According to the theory of nonequilibrium thermodynamics in social evolution, neither economic nor political reform should go ahead of the other. A calculated interplay may catch the chance to proceed with a reform program when technological breakthroughs and educational progress make the institutional transition feasible. The leader of China's reform or pro-modernization movement should always keep watching the changing international climate to decide whether it is the time to advance or compromise.

11 China's challenge to economic orthodoxy

Asian reform as an evolutionary, self-organizing process[1]

11.1 Introduction

Old beliefs often shatter on the rocks of historical events, and new thinking emerges from the wreckage. The twentieth century offers two such historical events: the Great Depression of the early 1930s and the collapse of the Soviet Union in the late 1980s. The Great Depression shook classical economics to its foundations, and gave birth to Keynesian economics. The transition from command to market economies in the 1990s, the other transcendent event of the twentieth century, and the rise of the Asian economies, may well have equally profound repercussions for economic dogma.

After the Berlin Wall fell in 1989, most observers predicted that the twenty-first century would be a European century, led by a unified Germany's financial capital and high technology and a Russia rich in human capital and natural resources. China was seen as a coming source of turbulence because of chronic poverty and population pressure. The big-bang prescription for Eastern Europe and the former Soviet Union (EEFSU) – wholesale privatization, rapid liberalization – was hailed as the optimal design for quick conversion from command to market systems, while China's experimental approach – controlled decentralization and gradual liberalization – was criticized as a half-hearted reform full of traps and contradictions.

But historical realities, like rocks beneath the waves, threaten to shatter the theories with which these social scientists and policy makers have embarked. After trying various sorts of shock therapy, and huge injections of Western aid, the economies of Eastern Europe and Russia are still in persistent decline.

Consider the following contrast in cost–benefit calculation.

Transfer payments to eastern Germany now amount to about 50 percent of that region's GNP (or 8 percent for western Germany). These are huge amounts compared with the Marshall plan, which was barely 2 percent of Western European GNP. Yet, despite the transfers, GNP in eastern Germany has declined over 40 percent (Schrenk 1993). Meanwhile, the huge cost of German reunification has prolonged the recession in the Western economies, and delayed European integration (Summers 1991; Marsh 1993).

In contrast, China has received little foreign aid during its economic transition. The largest source of foreign capital has come from Hong Kong (and overseas Chinese), but roughly the same amount of Chinese capital has flowed outward into Hong Kong. Accumulated foreign investment in China was $33 billion in 1992, or only $28 per capita (Gao 1993). The Chinese level of foreign aid and foreign capital inflows per capita is miniscule – 4 percent that of Poland, 0.3 percent that of eastern Germany, despite their higher per capita GNP. And in return for this much more modest investment, we observe in China over the last 14 years an average growth rate in GNP of 9 percent, and in exports of 13 percent.

Can we explain the spectacular rise of the Chinese economy, and the mysterious fall of the Russian and Eastern European economies, using neo-classical or endogenous growth theory? Alas, only a few economists recognize the need to fit the Chinese experience into mainstream economics (Singh 1991; Amsden 1993). Most mainstream economists still set China aside, on the grounds of different initial conditions or cultural traditions (Bogetic 1991; Hirschler 1991).

To some extent, this may reflect the primacy of political over economic concerns. In the current debate over big bang versus gradualism, both sides accept as the primary goal, not the growth-with-stability at which China excels, but rather the rapid and permanent displacement of the command economy by the Western-type market economy, as a political end in itself (Islam 1993). Within this sort of cost–benefit calculus, China's experience drops out of the equation.

But does Asia have no lessons to teach us? Alan Blinder once observed that the rise of the Japanese economy posed a serious challenge to the neo-classical model based on the Western market economy, since Japan had succeeded by doing everything "wrong" (1990). For example, the Japanese stood on its head the American paradigm of serving the consumer, searching for profit, benefiting stockholders, and seeking free trade. Blinder's observation reminds us that China's experience in development strategy and institutional reform may have lessons for developing and developed countries both.

Consider some challenging Chinese paradoxes. How, within the neo-classical model, can we explain the fast growth of township and village enterprises, which have no clearly defined property rights and yet play a dynamic role in economic growth and community development? How will we fit into traditional micro and macro analysis the catalytic role played in China by provincial, county, and even village government?

Consider China's approach to improving the efficiency of state enterprises. Privatization in this area is feasible only for small-scale firms; for larger firms, especially in heavy and defense industries, this approach is much more problematic (Lipton and Saches 1990; Sachs 1992). Here, China improved large-scale state sector efficiency mainly by introducing competitive pressure from the growing non-state sector.

The current crisis of the Western economies is deeply rooted in the Western tradition of unchecked individualism, excessive welfare provision, unequal income distribution, and insufficient provision of public infrastructure designed to meet the challenge of global competition and technological change (Bellah *et* *al.* 1985; Etzioni 1988; Daly and Cobb 1989). Is there a parallel crisis in economic orthodoxy? A careful study of the experience of Asian economies may stimulate fresh thinking in economic science and public policy.

This chapter suggests one such lesson, having to do with the nature of institutional change. Section 11.2 argues that the success of Chinese reform stems not so much from its gradualism as from its decentralized approach. Section 11.3 extends this argument, suggesting that decentralized change is effective because economic institutions must be self-organizing. Section 11.4 suggests even broader implications for the nature of economic growth and the need for paradigmatic change in economics.

11.2 Rational design versus decentralized experiment

To characterize the reform debate as "big bang versus gradualism" is misleading. The important choice posed by competing reform strategies today is between the experimental, decentralized Chinese approach and the top-down, designer approach of Russia and Eastern Europe. Prior to 1989, after all, reform in Hungary, Poland, and elsewhere was amply gradual; indeed, it was the failure of that very gradualism which precipitated the radicalism of today (Hirshler 1991). The constant feature of Eastern European reform efforts, both before and after 1989, was that reform measures were designed centrally and then prescribed in a top-down fashion.

China's reforms have been gradual but, more importantly, they have consistently followed an experimental approach. Examples include the rapid quasi-privatization in rural areas (the family responsibility system), a series of mini-big-bang price and trade liberalizations in the special economic zones (SEZs), the two-tier system for prices and exchange rates, and gradual, diverse institutional reforms in the state sector. Government leaders, including radical reformers, were initially suspicious of many of these non-orthodox practices, such as the family contract system, the "illegal competition" of village enterprise, and even the SEZs. Formal institutional changes typically lagged several years behind successful experiments and widespread imitation.

In this process, the most important contribution of China's reform leadership was that they refrained from making quick judgments and suppressing "illegal" practices; instead, they let time be the judge. This tolerance of heterodoxy fostered innovation in institution building. The "gradualness" of China's reform, then, was not a conscious design of the central government, but rather the inevitable result of compromises among a myriad of conflicting proposals, through a long process of trial and error. China's success demonstrates the effectiveness of providing time for learning and adaptation, rather than importing foreign systems overnight.

11.3 Decentralized social change and paradigm conflict in economic science

Why is it that a decentralized, bottom-up, experimentally based approach to reform brought China institutional change at much lower social cost than reforms elsewhere? This section argues that the lack of confidence felt by liberal reformers in EEFSU led them to choose imported over home-grown solutions; but that the enormous uncertainties inherent in social change make this approach a high-cost one in the end. The fact that top-down "designer reform" is nonetheless being prescribed by Western economists reflects their failure to recognize the limitations of the neo-classical, "equilibrium" paradigm in our discipline.

The big-bang approach to transition put the highest priority on privatization, liberalization, and macroeconomic stabilization. That is, these liberal reformers sought a rapid "return to Europe" by adopting the legal framework of private property, importing the world trade price structure through liberalization, and imposing harsh stabilization policies softened by huge foreign loans (Sachs 1992). In all three ways, this approach in effect amounted to importing a whole structure from the outside world, rather than stimulating a gradual development of new institutions and forces within the existing economy.

This approach, which assumes a high degree of transferability of institutions from one society to another, reflects the underlying paradigm of modern economics – an equilibrium oriented approach that says, "Get the prices right, and the rest will follow." But in reality, social change is a complex, path-dependent, and unpredictable process (Stark 1992). Great uncertainty exists during the bifurcation and transition stage (Chen 1987a, 1990), particularly for large countries like Poland and Russia. This uncertainty translates to a high risk of expensive errors when coupled with the high cost of any social restructuring (the eastern German experience makes it clear how very high these costs can be).

Big-bang proponents like to argue that "you cannot leap over a chasm in two steps." But what if you leap and then discover that you're even farther on the wrong side of a chasm? Chinese reformers counsel instead that "you can only walk across a river by feeling first for the stones." This clash of metaphors reflects a difference in the underlying paradigms. The former approach, based on the Newtonian paradigm of classical mechanics, believes that after shock therapy knocks the economic system out of the orbit provided by central planning, the forces which move individual markets toward an equilibrium position can and will steer the entire economic system into a new, stable regime.

Few have questioned the analytic foundations of this belief (Murrel 1991; Stark 1992). But the new discovery of chaos in dynamic systems suggests that they are far more unpredictable than this, more complex, and more subject to instability, explosive oscillation, or chaos (Day and Chen 1993). "Rational designers" are oversimplifying complex, nonlinear aspects of social systems, and are also overlooking the bounded rationality of human behavior (Prigogine 1993).

11.4 Nonequilibrium economics, positive feedback, and growth

The foregoing has argued that equilibrium economics is an inappropriate paradigm for anticipating the path, which social institutions will take when they change rapidly; and that policies based on that paradigm may therefore fail. But in what sense does dynamic economics had better capture these processes? To answer this question, we must consider the catalytic role of positive feedback mechanism (Buchanan 1991).

The traditional theory of equilibrium economics emphasizes the role of negative feedback mechanisms in achieving equilibrium and stability. Excess supply generates rising unsold stocks, which leads price to fall, deceasing excess supply. Any positive feedback is viewed as destructive: it will cause increasingly large deviations from equilibrium.

But Pareto equilibrium is a static concept; no growth occurs. Yet, growth is a crucial ingredient of rapid but stable social change. It provides the lubricant, which reduces social friction, the expanding pie with which to buy off injured constituencies. Growth, in turn, depends on innovation, and the driving force behind innovation is the presence of some positive feedback mechanism.

One classic case of positive feedback generating path-dependent growth is the story of Silicon Valley (Arthur 1989, 1990). But China's experience abounds in similar examples – the family responsibility system in poor, rural inland areas, the SEZ experiment in rich, urban coastal areas, foreign investment in joint ventures, all interacting with each other through waves of positive feedback: communication, learning, imitation. The tiny absolute size of foreign investment, relative to its large result, strongly suggests that the underlying process is catalytic in nature.

To summarize: a complete picture of the social change and economic development, which China is experiencing, must include not just negative but also positive feedbacks. The new science of evolutionary self-organization reveals the constructive role played by positive feedback mechanism in a world of nonlinearities and uncertainty. It sheds new light on the catalytic mechanism and on how order emerges under nonequilibrium conditions (Nicolis and Prigogine 1977, 1989; Day and Chen 1993). Endogenous growth theory may add a further dimension: the role of catalytic mechanism in emerging new technology and new organization through non-optimization dynamics under nonequilibrium conditions. These are the lessons, which the historic events of the waning twentieth century will eventually provide to economic science.

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Part IV

Equilibrium illusion and meso foundation

Perpetual motion machine, representative agents, and organization diversity

12 The Frisch model of business cycles

A spurious doctrine, but a mysterious success[1]

The great tragedy of Science – the slaying of a beautiful hypothesis by an ugly fact.

(Thomas H. Huxley, English evolutionary biologist (1870))

There's none so blind as they won't see.

(Jonathan Swift, Irish author 1667–1745 (1927))

12.1 Introduction

A central issue in business-cycle theory is the nature and origin of persistent business cycles. There are mainly two lines of economic thinking: the endogenous school and the exogenous school (Zarnowitz 1992). Schumpeter considered business cycles as the life rhythm of an economic organism (1939). Goodwin introduced the nonlinear and chaotic oscillator to describe persistent business cycles (1951, 1990). However, early evidence of economic chaos has received little interest in mainstream economics, because the existence of economic chaos may imply serious challenges to the foundations of equilibrium theory and parametric econometrics (Barnett and Chen 1988; Chen 1988a, 1993a, 1996a, 1996b; Brock and Sayers 1988). In contrast, the exogenous school represents mainstream economics since the 1930s; whose founder was Ragnar Frisch (Kydland 1995).

Hayek realized that empirical features of business cycles were difficult to understand by equilibrium theory (Hayek 1933). However, Frisch suggested that a noise-driven damped oscillator might explain both market stability and persistent cycles, which he claimed in an informal paper in 1933 (Frisch 1933). Contrary to Frisch's belief, physicists had known since 1930 that a harmonic oscillator under Brownian motion could not produce persistent oscillations (Uhlenbeck and Ornstein 1930; Wang and Uhlenbeck 1945). Today Frisch's belief is still widely held among economists and econometricians. Indeed, it is a mystery as to why Frisch never published his promised paper, and why the first Nobel Prize in economics was awarded to an unproved and wrong idea. Re-examining the Frisch model will help us to understand the origin of equilibrium belief in economic thinking.

In this chapter, we will give a brief history of the Frisch model, and then discuss its theoretical and empirical implications. We will show that the linear deterministic model of business cycles has structural instability. The effect of external noise to a linear oscillator can be studied by the Langevin equation and the Fokker–Planck equation. We may obtain the analytical solution for a harmonic oscillator under Brownian motion. Its exponential decay in amplitude and autocorrelations indicate that white noise is not capable of producing persistent cycles. We can directly estimate the intrinsic frequency and friction coefficient from real US GDP data. We then will discuss the main implications from the Brownian motion of a harmonic oscillator, and basic problems of the linear model of business-cycle theory.

12.2 Some historical notes on the Frisch model of business cycles

The Frisch model of business cycles has been a dominating influence in business-cycle theory since the 1930s. In an informal conference paper in 1933, Frisch suggested that the stable property of a market economy could be described by a damped oscillator, and that persistent business cycles could be maintained by persistent shocks (Frisch 1933). He said (the italics and bold are added by the author):

> When an economic system gives rise to oscillations, these will most frequently be damped. But in reality the cycles we have occasion to observe are generally not damped. *How can the maintenance of the swings be explained?*
>
> One way which I believe is particularly fruitful and promising is to study what would become of the solution of *a determinate dynamic system if it were* ***exposed to a stream of erratic shocks*** *that constantly upsets the continuous evolution, and by so doing introduces into the system* ***the energy necessary to maintain the swings***…
>
> I shall offer some remarks on these questions. *For a more detailed mathematical analysis the reader is referred to* ***a paper to appear*** *in one of the early numbers of* ***Econometrica***.

Readers should be aware that the above statement is an explicit design of perpetual motion machine of the second kind, which could convert random (heat) energy from environment fluctuations into mechanic work by overcoming friction force. This machine violates the second law of thermodynamics.

After a detailed discussion on the propagation problem of damped oscillators and an intuitive discussion on the impulse problem of noise impacts, Frisch declared:

> *It is reasonable to speak of an average period and an average amplitude.* In other words, there is created just the kind of curves which we know from

> actual statistical observation. I shall not attempt to give any ***formal proof****, together with* ***extensive numerical computations****, will be given in the above mentioned paper* ***to appear in Econometrica***.

The following title did appear in *Econometrica* three times under the category "Papers to Appear in Early Issues: … Ragnar Frisch: Changing Harmonics Studied from the Point of View of Linear Operators and Erratic Shocks."

The statement appeared in Volume 1 of *Econometrica*, including Issue No. 2 (April 1933), page 234; Issue No. 3 (July 1933), page 336; and Issue No. 4 (October 1933), page 448; but it disappeared from Volume 2, Issue No. 1 (January 1934). The promised paper never did appear. This incident could have happened because Frisch himself was the editor of the newly established flagship journal for the Econometric Society.

Thirty-six years later, Frisch shared the first Nobel Prize in economics for his work in business-cycle theory. In October 1969, Professor Erik Lundberg made the following statement on behalf of the Royal Swedish Academy of Sciences (the italics are added by the author):

> *Professor Frisch's pioneer work in the early thirties involving a dynamic formulation of the theory of cycles*. He demonstrated how a dynamic system with difference and differential equations for investment and consumption expenditure, with certain monetary restrictions, produced *a damped wave movement* with wavelengths of four years and eight years. *By exposing the system to random disruptions, he could demonstrate also how these wave movements became permanent and uneven in a rather realistic manner.* ***Frisch was before his time*** *in the building of mathematical models*, and he had many successors. The same is true of his contribution to methods for the statistical testing of hypotheses.
>
> (Lundberg 1969)

In his speech delivered in Stockholm in June 1970, Frisch talked at length on everything from alchemy to particle physics, but never mentioned his prize-winning model of business cycles (Frisch 1981). From the above facts, we can speculate that Frisch quietly abandoned his model as early as 1934 but never made his view public.

Lundberg was wrong when he declared that "Frisch was before his time." In fact, physicists solved the problem of the harmonic oscillator under Brownian motion in 1930 and refined in 1940s (Uhlenbeck and Ornstein 1930; Chandrasekhar 1943; Wang and Uhlenbeck 1945). The classical works on Brownian motion were well known among mathematicians through the influential book on stochastic process (Wax 1954). All these physicists reached the same conclusion that Brownian motion was not capable of maintaining persistent harmonic cycles. Since 1963, the discoveries of deterministic chaos further indicate that only the nonlinear oscillator is capable of generating persistent cycles (Lorenz 1963; Hao 1990).

It was a great mystery why the economic community has for more than six decades ignored these fundamental results in stochastic process and adhered to the mistaken belief of noise-driven persistent cycles. It is not difficult to see why damped harmonic cycles cannot be maintained by external shocks.

12.3 Structural instability of linear deterministic cycles

Frisch was quite aware of the limitation of linear cycles (Goodwin 1993). It is known that simple harmonic cycles can be generated by a second-order linear differential equation or difference equation. However, periodic cycles exist only when friction is zero. Any deviation in parameter space may change a harmonic cycle into damped or explosive oscillation. This phenomenon is called structural instability in mathematical modeling.

12.3.1 Samuelson model in discrete time

A typical example of linear cycle is the Samuelson model of multiplier-accelerator (Samuelson 1939). The original version of the Samuelson model is in discrete-time:

$$C_t = aY_{t-1}$$

$$I_t = b(C_t - C_{t-1})$$

$$Y_t = C_t + I_t + E$$

Where $0 < a < 1$, and $b > 0$, C is consumption; I, investment; E, government expenditure; and Y is income. We have a second-order difference equation:

$$Y_t - a(1+b)Y_{t-1} + abY_{t-2} = E$$

Its solution is

$$Y_t = \frac{E}{1-a} + c_1(\lambda_1)^t + c_2(\lambda_2)^t$$

where λ_1 and λ_2 are two roots of the characteristic equation

$$\mathrm{A}(\lambda) = \lambda^2 - a(1+b)\lambda + ab = 0$$

Its discriminant is

$$\Delta = a^2(1+b)^2 - 4ab$$

$$a = \frac{4b}{(1+b)^2} \qquad \text{when } \Delta = 0 \tag{12.1a}$$

We have oscillation solutions when $\Delta < 0$.

The condition for a periodic solution is

$$ab = 1 \tag{12.1b}$$

From economic consideration, we must have

$$0 < a < 1, \text{ and } b > 0 \tag{12.1c}$$

The equations (12.1a, b, and c) consist of main boundaries of pattern regimes. The model has four types of solutions: (i) damped oscillation regime DO; (ii) explosive oscillation regime EO; (iii) monotonically converging regime MC; (iv) monotonically increasing regime MI. Periodic oscillation regime PO occurs only at the borderline between DO and EO regimes. Patterns in the parameter space are shown in Figure 12.1. As we said before, the periodic oscillation PO is only marginally stable in the parameter space.

12.3.2 Samuelson model in continuous time

The continuous-time model of business cycles was also studied in economics (Scarfe 1977). Here, we discuss the continuous-time version of the above Samuelson model to demonstrate the relation between discrete-time and continuous-time linear models. We simply replace the difference by the derivative in the Samuelson model. We have:

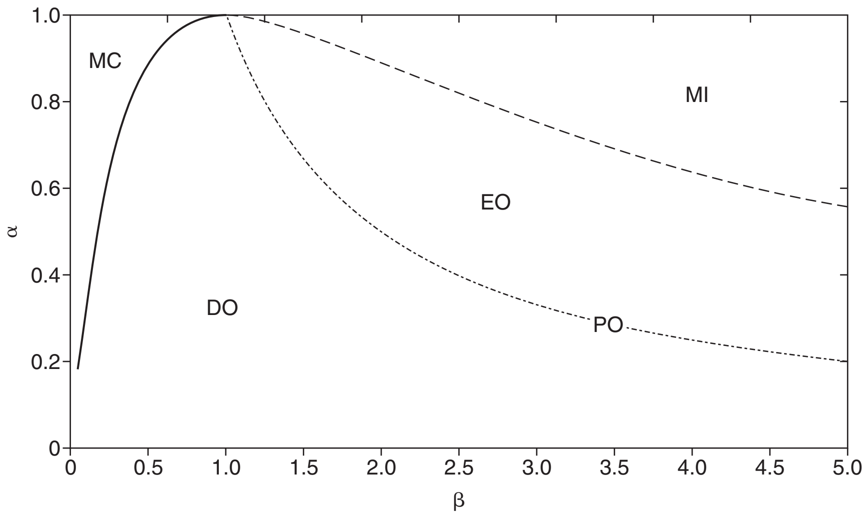

Figure 12.1 Pattern regimes of the discrete-time Samuelson model in parameter space.

Notes

MC stands for monotonic converging; DO, damped oscillation; PO, periodic oscillation; EO, explosive oscillation; MI, monotonic increasing.

$$C(t) = a[Y(t) - Y'(t)]$$

$$I(t) = ab[Y'(t) - Y''(t)]$$

$$Y(t) = C(t) + I(t) + E$$

We have a second-order differential equation

$$Y''(t) + \frac{1-b}{b} Y'(t) + \frac{1-a}{ab} Y(t) = E$$

$$Y(t) = \frac{ab}{1-a} E + c_1 e^{\lambda_1 t} + c_2 e^{\lambda_2 t}$$

where λ_1 and λ_2 are two roots of the characteristic equation (12.2)

$$A(\lambda) = \lambda^2 - \frac{1-b}{b} \lambda + \frac{1-a}{ab} = 0 \qquad (12.2)$$

When $\lambda_1 = \lambda_2 = \lambda$, we have

$$Y(t) = \frac{ab}{1-a} E + (c_1 + c_2 t) e^{\lambda t}$$

We have a periodic solution only when $b = 1$. Similarly, this continuous-time model also has four dynamic regimes. Its pattern regimes are shown in Figure 12.2. Compared with the discrete-time Samuelson model, the only difference is the changing of the periodic border. The periodic oscillation is still marginally stable in the parameter space.

12.4 Brownian motion for a harmonic oscillator

The Frisch model in economics is studied as the Brownian motion of a harmonic oscillator in physics. In his 1933 paper, Frisch only discussed a damped oscillator in terms of the following equation:

$$\frac{d^2 x(t)}{dt^2} + \kappa \frac{dx(t)}{dt} + \omega^2 x(t) = 0$$

Frisch knew that this equation could produce a damped oscillation with angular frequency ω when the friction coefficient κ was not zero. By adding a series of random shocks, the Frisch model would become the Brownian motion of a harmonic oscillator, which was a natural extension of the Brownian motion of a free particle. The question is whether Brownian motion can maintain the persistent oscillation of a harmonic oscillator.

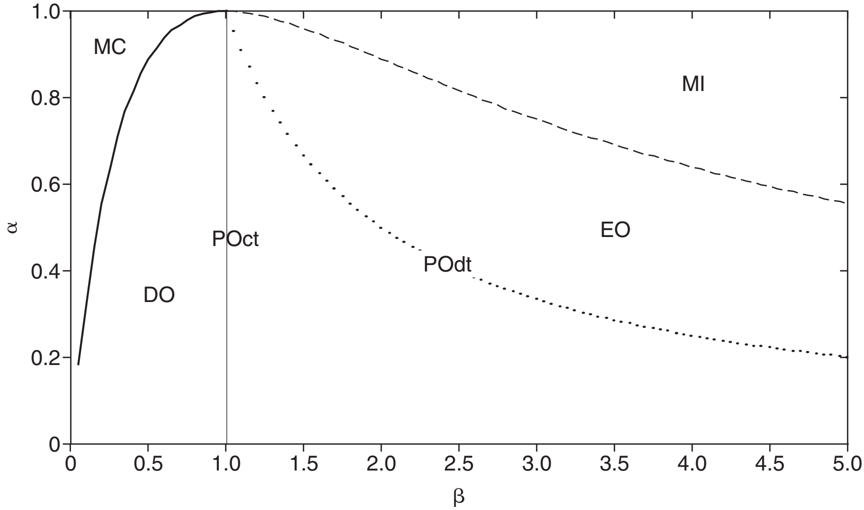

Figure 12.2 Pattern regimes of the continuous-time Samuelson model in parameter space.

Note
The periodic boundary shifts from POdt to POct.

The theory of Brownian motion for a free particle was solved by Einstein in 1905 (Einstein, 1926 for English translation). The Brownian motion theory of a harmonically bound particle was solved in 1930 and refined in the 1940s (Uhlenbeck and Ornstein 1930; Chandrasekhar 1943; Wang and Uhlenbeck 1945). Their main finding was that the harmonic particle would produce a damped harmonic oscillation under random shocks. We introduce the Langevin equation and the corresponding Fokker–Planck equation to address this issue.

The movement of a harmonic particle can be described by the following equation:

$$\frac{d^2x(t)}{dt^2} + \kappa\frac{dx(t)}{dt} + \omega^2 x(t) = \Xi(t)$$

$$< \Xi(t_1)\,\Xi(t_2) >= 2\Gamma\delta(t_1 - t_2) \quad \text{where} \quad 2\Gamma = \sigma^2$$

Where $x(t)$ is the coordinate,

$$\frac{dx(t)}{dt}$$

is the velocity of the particle, and $\Xi(t)$ is a continuous-time Gaussian white noise with zero mean and standard deviation of σ, Γ is diffusion coefficient, and κ is friction coefficient.

The Langevin equation can be transformed into a Fokker–Planck equation:

$$\frac{\partial P(x,v,t)}{\partial t} = -v\frac{\partial P(x,v,t)}{\partial x}$$

$$+\frac{\partial}{\partial v}[(\kappa v + \omega^2 x) P(x,v,t)] + \Gamma\frac{\partial^2 P(x,v,t)}{\partial v^2}$$

$$v = \frac{dx}{dt}$$

$$P(x,v,0) = \delta(x - x_0)\delta(v - v_0)$$

This equation can be analytically solved. We can calculate its average displacement and correlations. We have

$$< x > = \frac{v_0}{\omega_1}\exp\left(-\frac{\kappa t}{2}\right)\sin(\omega_1 t)$$

$$+\frac{x_0}{\omega_1}\exp\left(-\frac{\kappa t}{2}\right)\left[\omega_1\cos(\omega_1 t) + \frac{\kappa}{2}\sin(\omega_1 t)\right]$$

$$\Rightarrow 0 \quad \text{when } t \to \infty$$

Where angular frequency ω and frequency f are associated by $\omega = 2\pi f$, the intrinsic angular frequency ω can be obtained from the characteristic equation. For the realized angular frequency ω_1, we have:

$$\omega_1^2 = \omega^2 - \frac{\kappa^2}{4}$$

We can calculate the mean square displacement of the harmonic particle (Wang and Uhlenbeck 1945):

$$< (x - < x >)^2 > = \frac{\Gamma}{\kappa\omega^2}$$

$$-\frac{\Gamma}{\kappa\omega^2}\frac{1}{\omega_1^2}\exp\left(-\frac{\kappa t}{2}\right)\left[\omega_1^2 + \frac{\kappa^2}{2}\sin^2(\omega_1 t) + \frac{\kappa\omega_1}{2}\sin(2\omega_1 t)\right]$$

$$\Rightarrow \frac{\Gamma}{\kappa\omega^2} \quad \text{when } t \to \infty$$

$$< x(t)x(t+\tau) > = \frac{\Gamma}{\kappa\omega^2}\exp\left(-\frac{\kappa t}{2}\right)\left[\cos(\omega_1\tau) + \frac{\kappa}{2\omega_1}\sin(\omega_1\tau)\right] \qquad (12.3)$$

Here, τ is the time delay.

From Einstein, we know the Brownian motion of a free particle has a different result (Einstein 1926):

$$< s^2 >= 2\Gamma t \tag{12.4}$$

Both of the equations (12.3) and (12.4) were verified by experiments (Barnes and Silverman 1934). We can see then that a harmonic oscillator under the Brownian motion does not lead to a diffusion process. Its oscillation will have become rapidly damped into residual fluctuations without apparent periodic motion.

12.5 US business cycles as Brownian motion of a harmonic oscillator

The main features of a damped oscillation under Brownian motion can be estimated from its autocorrelations (Wang and Uhlenbeck 1945):

$$\rho(\tau) = \exp\left(-\frac{\kappa\tau}{2}\right)\left[\cos(\omega_1\tau) + \frac{\kappa}{2\omega_1}\sin(\omega_1\tau)\right]$$

The autocorrelations of displacement show damped oscillations with an exponential decay. We can define a relaxation time T_κ

$$T_\kappa = \frac{2}{\kappa}$$

We can see that the realized oscillating frequency is determined by the free intrinsic frequency and the friction coefficient. We can directly measure κ and ω_1 from the autocorrelations of empirical data. The noise-driven damped oscillator produces only short temporary cycles, whose life is in the order of T_κ. The realized harmonic frequency f_1 can be measured by the first zero point in autocorrelation:

$$\omega_1 = \frac{2\pi}{T_{ac}} \text{ and } T_{ac} = 4To,$$

$$\omega^2 = \omega_1^2 + \frac{\kappa^2}{4}$$

Because autocorrelations are a measure of a stationary process, we must choose the proper way to remove growth trends from the empirical time series. The choice of detrending represents a choice in the observation reference (Chen 1996a, 1996b). The first difference (FD) detrending in econometric analysis represents the smallest time window and a whitening filter. The log-linear detrending (LLD) represents the largest time window that covers a whole historical period. The Hodrick–Prescott (HP) filter defines a nonlinear smooth trend with a media time window (Hodrick and Prescott 1997; Kydland and Prescott 1982).

We can define a gain factor G that is the ratio of the residual variance to the noise variance:

$$G = \frac{< x^2 >}{\sigma^2} = \frac{2}{\kappa\omega^2}$$

From US Real GDP Quarterly Data (1947–1992), we have the following results in Table 12.1. Because the autocorrelations of the real GDP quarterly series are rapidly damped within only one or two cycles, so the errors of estimation are quite large. However, the magnitudes of these parameters are still reasonable to accept. Some qualitative features can be seen from the Table 12.1.

First, the harmonic oscillator will quickly cease its harmonic oscillation within one or two cycles, ranging from two to 40 years depending on your observation reference of business cycles. The relaxation time T_κ is the shortest for FD but the longest for LD. Clearly, random shocks cannot maintain persistent cycles of a damped oscillator.

Second, different time windows reveal different pictures of business cycles. The FD series has the smallest variance and the shortest period, while the LD cycle has the largest variance and the longest period. The variance and period of the HP cycles are between the FDs and LDs. Among them, only the FD filter has a damping effect to external noise. Both HP and LD filters have an amplifying effect to external noise. These features add additional difficulty to the choice of one's reference system in equilibrium economics.

Table 12.1 The Frisch model for US Real GDP cycles (time unit is year)

	κ	ω	ω_I	T	T_I	T_κ	σ	G
FDs	1.02	1.86	1.79	3.4	3.5	2.0	0.010	0.57
HPc	0.41	1.32	1.30	4.7	4.8	4.9	0.018	2.8
LDc	0.055	0.15	0.11	42.0	57.0	36.0	0.021	1600

Source: Federal Reserve Bank at St. Louis.

Notes
Where κ is the friction coefficient,
ω the angular frequency,
ω_1 the realized angular frequency,

$$T_1 = \frac{2\pi}{\omega_1}$$

the observed period,

$$T = \frac{2\pi}{\omega_1}$$

the intrinsic period, T_κ the relaxation time, σ the standard deviation, G the gain factor.

From the above features, we can see that the equilibrium perspective does not provide a unified approach in empirical analysis. Neo-classic growth theory implies the LD approach in economic growth (Solow 1956). Friedman preferred the FD to the LD approach because the LD introduces boundary dependence (1969). FD detrending is widely used in econometrics and financial analysis because of its white appearance. The problem of the FD approach is that it is hard to identify an external source of business cycles, which needs to be larger than the US economy!

12.6 Conclusion

The Frisch model of business cycles is not capable of understanding persistent cycles observed in market economies. Random walks cannot deliver sufficient energy to overcome friction because of the second law of thermodynamics. From Slutsky to Frisch, the nonlinear nature of persistent business cycles has been obscured by the mistaken belief in noise-driven business cycles (Slutsky 1937).

Certainly, the Frisch conjecture did raise many interesting questions about the impact of external noise on deterministic oscillators. So far as we know, persistent cycles can only be generated by nonlinear dynamical systems, such as limit cycle solution of the van der Pol model and chaos trajectory of the Rössler model (1976). External noise may change the stability pattern of a nonlinear oscillator when the noise level goes beyond some threshold (Chen 1987b).

It was a great mystery how a Nobel Prize was awarded to a false claim without theoretical analysis and empirical evidence. Scholars of the history of science may be interested in further questions, such as why Frisch gave up his promised paper and why he kept his silence about his model since 1934.

From our experience in studies of economic chaos, the main obstacle to the nonlinear and nonequilibrium perspective is some spurious doctrine in equilibrium thinking, such as the Frisch model. The wishful thinking of the Frisch model is quite similar to perpetual motion machine in the history of thermodynamics. Schumpeter considered business cycles like the heart beat, which was the essence of the organism (Schumpeter 1939). According to nonequilibrium thermodynamics, biological clock can only emerge in dissipative systems with energy flow, information flow, and matter flow (Prigogine 1980). Therefore, nonequilibrium mechanism is the nature of economic evolution, and nonlinear dynamics is the origin of business cycles. The one valuable lesson gained from the mystery surrounding the Frisch model is that an interdisciplinary dialogue between economists and other scientists would be fruitful for the science community.

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13 Microfoundations of macroeconomic fluctuations and the laws of probability theory

The Principle of Large Numbers vs. rational expectations arbitrage[1]

13.1 Introduction

The appropriate model for business cycle fluctuations with uneven growth trends is still an open issue in macroeconomics. There are two conflicting fundamental approaches to business-cycle theory: the exogenous-shocks-equilibrium school originating with Frisch (1933) and the endogenous-cycles-disequilibrium school originating with Samuelson (1939).

Lucas' (1972, 1981) call for a microfoundations of macroeconomics based on the exogenous-shocks-equilibrium approach has had a strong impact on business-cycle theory. Lucas emphasized two principles for equilibrium theory of business cycles. Optimal behavior should prevail at the micro level, and expectations should be formed rationally at the macro level. Lucas' approach implies that all unemployment and excess capacity is voluntary and optimal. The question this chapter addresses is, "Can Lucas' theory explain the observed magnitude of business cycle fluctuations?" The answer is, "NO."

There are mainly two versions of optimization-equilibrium theory of business cycles. In economic thinking, the new classical school led by Lucas mainly considers monetary shocks while the real business-cycle school (RBC) largely studies real (technological) shocks as the main source of external noise. In mathematical modeling, Lucas uses the island economy model of a stationary economy with many agents and the real business-cycle school works with the representative agent model in computational simulation (Kydland and Prescott 1982). In empirical studies, the new classical school follows the econometric convention of the log-linear (LL) detrending in regression analysis, while the real business-cycle school develops the HP filter for separating a nonlinear smooth trend and fluctuating cycles in macroeconomic movements (Hodrick and Prescott 1997). These two approaches to the microfoundations modeling of macroeconomic movements, however, have common problems: they ignore two fundamental issues, which are central to understanding the relationship between micro and macro dynamics in any system. Both Lucas and the RBC theory treat an essentially many-body problem as a one-body problem, and fail to appreciate the statistical nature of business fluctuations of prices and outputs that is changing over time.

It is a fundamental principle of empirical sciences that theory cannot be divorced from measurement. A natural measure of the fluctuation of positive data series (such as work hours and output in macroeconomic data) is the *relative deviation*, the ratio of the standard deviation of the series to its mean.[2] According to the law of large numbers and the central limit theorem, the relative deviation is in the order of

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

for a system with N independent elements. We will call this general rule the *Principle of Large Numbers*.[3] This principle immediately calls into question the idea of explaining macroeconomic fluctuations as the aggregation of microeconomic fluctuations. The number of households and firms in the US economy is so large that the aggregation of microeconomic variations will produce a relative deviation several orders of magnitude smaller than observed macroeconomic fluctuations.

This chapter focuses on Lucas' (1972) model of an island economy (the LMI model) as the benchmark model of the microfoundations approach in business-cycle theory and gives only a brief discussion of the RBC model with a representative agent. In modeling stochastic processes, we extend our scope from statistics theory with stationary probability distribution (i.e., the i.i.d. model in econometrics) to probability theory with nonstationary probability distribution (here we use the linear birth–death process) for understanding macroeconomic fluctuations with growth, so that our empirical analysis can be applied to both the new classical model and the RBC model of macroeconomic fluctuations.

In the next two sections of this chapter, we will show that the Principle of Large Numbers is valid for stationary stochastic process like the system of the LMI model as well as for the linear stochastic process of growth studied in the RBC literature (Kydland and Prescott 1990). There is little empirical evidence in favor of a microfoundation explanation of fluctuations in the US output and employment.

In section 13.4, we will discuss some theoretical issues raised by the LMI model. We will argue that, contrary to the claims of the LMI model, a rational expectations mechanism cannot be expected to generate perfectly correlated behavior among intelligent agents when they have market information and arbitrage opportunities. Certain fundamental factors underlying market movements, such as unequal distribution, economic complexity, and multiple time scales, cannot be ignored in business-cycle theory, as the LMI theory seems to claim.

The equilibrium framework based on microfoundations, rational expectations, and efficient markets is therefore not capable of providing a consistent explanation of business cycles. We must consider other alternatives, including the idea that the macroeconomy is undergoing chaotic deterministic dynamics and the idea that structures intermediate (financial intermediate and industrial organization) between micro (households and firms) and the macro economy play a crucial role in business-cycle fluctuations.

13.2 Some statistical background

In this section, some statistical background is reviewed for discussing the micro–macro relation in business fluctuations. The concept of relative deviation for positive random variables is analyzed for stationary and nonstationary stochastic process. The pattern of

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

emerges when N is large.

13.2.1 The relative deviation of a positive random variable

A basic measure of the fluctuation of a random variable X with a finite mean m and higher moments is the *relative deviation*, Ω is defined by the ratio of its standard deviation σ to its mean m,

$$\Omega = \frac{\sigma}{\mu} = \frac{\sqrt{< (X - < X >)^2}}{< X >}$$

where $<X>$ represents the expectation of the variable X. The relative deviation provides a useful measure of the order of fluctuations, which is valid when the mean is not zero. This is certainly true for a *positive* variable. There is a wide class of positive variables in physics and social sciences, such as density, energy, population, output, and working hours. Their values are non-negative so that their means are always greater than zero.

Consider some examples in statistics. The relative deviation for a point distribution is zero, for a two-point distribution is one, and for the uniform distribution over the unit interval,

$$\Omega_{uniform} = \frac{1}{\sqrt{3}} \approx 0.577.$$

About 99.7 percent of the Gaussian distribution falls within the range (m – 3σ, m + 3σ). In order to regard a Gaussian random variable as a positive variable, therefore, we must have (m – 3σ) > 0, so we have

$$0 < \Omega_{Gaussian+} = \frac{\sigma}{m} < \frac{1}{3} \tag{13.1}$$

13.2.2 The relative deviation in a system of two positive variables

Let's consider a system S_2 with only two variables X and Y. Its covariance and correlation coefficient are:

$$COV(X,Y) = <(X-<X>)(Y-<Y>)> = <XY> - <X><Y>$$

$$\rho = \frac{COV(X,Y)}{\sigma_x \sigma_y}$$

where σ_x and σ_y is the standard deviation for X and Y respectively.

We can calculate correlation coefficients for two extreme cases. When X and Y are independent variables, we have $<XY> = <X><Y>$ and $\rho = 0$. When X and Y are linear dependent, then, X, Y are perfectly correlated and $\rho = 1$. If we further assume that X and Y have the same mean m and variance σ^2 for simplicity, then, X and Y must be identical to have perfect correlation. These facts are useful in calculating the relative deviation of the system S_2. We have

$$<S_2> = 2m$$

$$<S_2^2> = <X^2 + Y^2 + 2XY> = 2<X^2> + 2<XY> = 2\sigma^2 + 2m^2 + 2<XY>$$

$$VAR[S_2] = <S_2^2> - <S_2>^2 = <S^2> - 4m^2 = 2\sigma^2 - 2m^2 + 2<XY>$$

$$<XY> = <X>^2 = m^2 \qquad \text{when X, Y are independent}$$

$$<XY> = <X^2> = m^2 + \sigma^2 \qquad \text{when X, Y are identical}$$

For the case of independent X and Y, we have $VAR[S] = 2\sigma^2$, so that

$$\Omega_2 = \frac{\sqrt{VAR[S_2]}}{<S_2>} = \frac{1}{\sqrt{2}}\frac{\sigma}{m} = \frac{\Omega}{\sqrt{2}} \text{ when X and Y are independent}$$

For the case of identical X and Y, we have $VAR[S_2] = 4\sigma^2$, so that

$$\Omega_2 = \frac{\sqrt{VAR[S_2]}}{<S_2>} = \frac{\sigma}{m} = \Omega$$

We can see that the relative deviation of a macro system with two elements is smallest with independent elements and largest with perfectly correlated elements. This result is perceivable since two independent fluctuations will partially cancel out each other. We can easily generate this result to a system with more elements.

13.2.3 The relative deviation in a system of many positive variables

Now, consider a stationary macro system with N identical positive elements, with values X_i, where i = 1, 2,… N. The sum describing the macro system is $S_N = X_1 + \ldots + X_N$. We assume that fluctuations in each positive variable follow an identical distribution, with mean m and standard deviation σ. According to the law of large numbers in probability theory, the mean of the macro system is Nm. Based on the central limit theorem, the variance of the macro system is $N\sigma^2$. Therefore, the relative deviation Ω for the macro system is

$$\Omega_{N,ST} = \frac{\sigma\sqrt{N}}{Nm} = \frac{\varpi_{ST}}{\sqrt{N}} \sim \frac{1}{\sqrt{\text{N}}} \tag{13.2}$$

From equation (13.1), we have

$$0 < \varpi_{ST} = \varpi = \frac{\sigma}{m} < \frac{1}{3}$$

Here, ST denotes a stationary probability system without growth; $\Omega_{N,ST}$ stands for the relative deviation at macro level with N elements; ϖ_{ST} stands for the relative deviation for just one element at micro level. Thus ϖ_{ST} is a finite constant, which is less than one. We will drop ST for simplicity thereafter. Therefore, the relative deviation of aggregated fluctuations with N positive independent elements must be on the order of

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

which can be applied when correlations among system elements are very weak.

The variance of the macro system will be much larger, however, when the correlations among micro elements are not near zero. Similar to the calculation in section 13.2.2, we may easily calculate the extreme case of perfect correlations.

$$< S >= Nm$$

$$< S >^2 = N^2(\sigma^2 + m^2)$$

$$VAR[S] = < S^2 > - < S >^2 = N^2\sigma^2$$

Because the variance of the macro system with N perfect correlated (denoted by pc) elements is on the order of $N^2\sigma^2$, then its relative deviation has the same magnitude of the relative deviation of its micro variable.

$$\Omega_{N,ST(pc)} = \frac{\sigma}{m} = \Omega \text{ when } \mathrm{X_i}, \mathrm{X_j} \text{ are identical}$$

Clearly, the pattern of

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

can only apply to a system, whose elements are close to statistically independent. If there are some correlations among elements, then we may construct a system of N clusters, if correlations among clusters are zero.

13.2.4 A nonstationary stochastic process

If we apply the stationary Principle of Large Numbers to macroeconomic data, we face the theoretical problem that a growing economy is not a stationary process. Let us therefore consider a finite-state stochastic process to represent internal fluctuations in a growth process. We assume the existence of a population of individuals.

Therefore, the case of exponential growth can be treated as a birth–death process with a constant growth rate $g = b - r$, where g is the growth rate, b the birth rate, and r the removal (death) rate. The probability of a state n occurring at time t is denoted $P(n, t)$. Its rate of change with respect to time t is proportional to the population size n:

$$\frac{\partial P(n,t)}{\partial t} = b(n-1)P(n-1,t) + r(n+1)P(n+1,t) - (b+r)nP(n,t) \tag{13.3}$$

Suppose the system is in the state of n at time t, i.e., $P(n, t)$. There are four possibilities for a change in the proportion of subsystems in state n: a subsystem could move from state $(n - 1)$ to n through a birth process, or from state $(n + 1)$ to n through a death process. Similarly a system could exit state n to $(n - 1)$ through a death process or out of state n to $(n + 1)$ through a birth process. We can calculate the mean and variance of the distribution over n once we have the analytic solution of $P(n, t)$ (Reichl 1998):

$$m_{BD} = < n(t) > = \sum_n nP(n,t) = N_0 * e^{gt} \tag{13.4a}$$

$$\sigma_{BD} = < n(t) - < n >>^2 = \sum_n (n - < n >)^2 P(n,t) = N_0 * \left(\frac{b+r}{b-r}\right) e^{2gt}(1 - e^{-gt}) \tag{13.4b}$$

Here N_0 is the initial population of the system.

The relative deviation of this system is:

$$\Omega_{BD} = \frac{\sigma_{BD}}{m_{BD}} = \frac{\sqrt{\left(\frac{b+r}{g}\right)(1 - e^{-gt})}}{\sqrt{N_0}} \Rightarrow \frac{\Omega_g}{\sqrt{N_0}} \sim \frac{1}{\sqrt{N}} \tag{13.5}$$

Their mean follows the same law of motion as a deterministic constant growth process. Comparing equation (13.5) to equation (13.2), the nonstationary stochastic model of growth introduces the new standard deviation σ_{BD}. But this factor cannot change the general conclusion that the relative deviation grows inversely with the square root of N.

Consider a reasonable case of an annual growth rate $r = 4$ percent and $t = 20$ years. We have $\Omega_g = 0.7421$ if $r = 0$, or $\Omega_g = 1.0494$ if $r = 0.02$ and $b = 0.06$. These figures show that the Principle of Large Numbers is also applicable for a linear stochastic system with growth.

13.2.5 Implied number of degrees of freedom and potential relative deviation

The Principle of Large Numbers suggests two useful statistics for the empirical analysis of micro–macro relations.

In a decentralized market economy, households, workers, and firms make their own economic decision. As a first approximation, we may consider a macroeconomic system consists of N independent agents, where N is the number of economic units. We define the *implied number of degrees of freedom*, N^*, as the number of independent micro positive variables that would produce the observed relative deviation of the macro variable, given the observed mean and standard deviation in a macroeconomic indicator:

$$N^* = \frac{1}{\Omega_{macro}{}^2} = \frac{m_{macro}{}^2}{\sigma_{macro}{}^2}$$

Thus the implied number of degrees of freedom tries to back out the number of independent micro level processes that could produce the observed magnitude of macro level fluctuations.

Alternatively, if we know the actual number *Nmicro* of microscopic elements in a macroscopic system, we can estimate the *potential relative deviation* Ω^* as the relative deviation we would expect to see in the macro fluctuations on the basis of the Principle of Large Numbers:

$$\Omega^* = \frac{1}{\sqrt{N_{micro}}}$$

We should keep in mind that the implied number of degrees of freedom N^* is not an exact figure but an order of magnitude, since we do not have a uniform relative deviation from various sources of micro data. We use these figures to infer the effective cluster number of elements in a micro–macro statistical model. We take out the constant in our evaluation of relative deviation for simplicity, since we are only interested in a rough estimation of the possible order of magnitude.

In empirical analysis, we may find the situation where the implied number from empirical fluctuations may be much smaller than the actual number of elements. There are two possible scenarios: if the difference between implied and actual number is not very large, it indicates that the system elements are weakly correlated. The Principle of Large Numbers is still useful to provide a lower bound of number of elements. If the difference is very large, then we should consider structural analysis in micro–macro relation. The underlying dynamics could be a mixed process with deterministic and stochastic patterns. We will see both possibilities in analyzing the US macro data.

13.3 The empirical order of relative deviations and theoretical implications for business cycles

Based on the above discussion, we need to examine the empirical order of relative deviation in the US economy and discuss potential sources of the observed business fluctuations.

13.3.1 Detrending methods and observing windows

A salient character of most macroeconomic time series is their uneven growth trend (Figure 13.1). Any practical measurement of business cycles must be based on a specific detrending method so that we can identify some regularity in a non-stationary time series. In the econometric literature, we find three such methods, which result in different estimated magnitudes of the cyclic components of

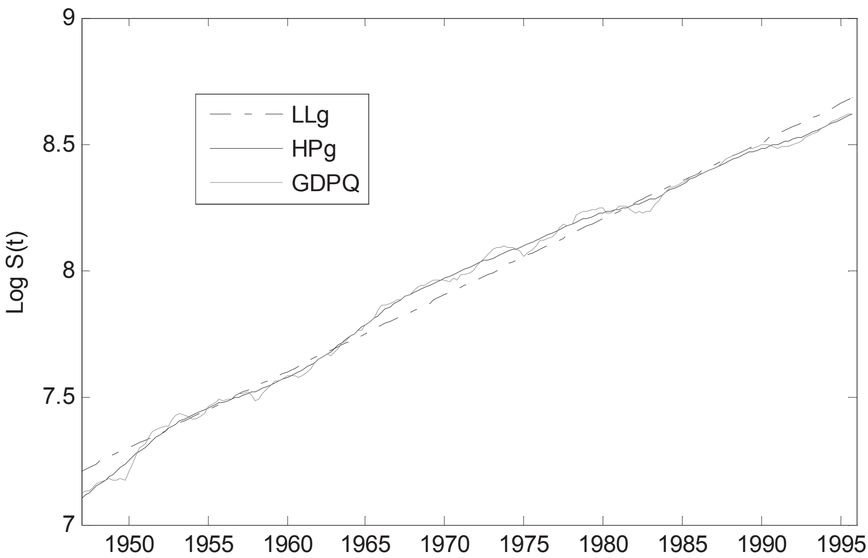

Figure 13.1 The GDPQ quarterly time series with LL and HP trends.

Notes
The grey line is the original logarithmic GDPQ time series (1947Q1–1995Q4); the dashed line is the log-linear trend (LL); the solid line is the Hodrick–Prescott (HP) trend. Data source is Citibase. N = 196.

various macroeconomic time series. Log-linear (LL) detrending assumes the data follows a constant exponential trend over the whole period. The HP detrending estimates a nonlinear smooth trend (Hodrick and Prescott 1997), which makes cyclic movements around the smooth trends fall within the frequency range of NBER (National Bureau of Economic Research) business cycles of about two to ten years with averaging cycle about four or five years. First differencing (FD) allows the underlying trend rate of growth to change in each measurement period so that fluctuations tend to look like white noise. FD uses the shortest time window (just the time unit of a time series), and LL the longest (the full length of the time series). The effective window for the HP method depends on the smoothing parameter chosen which is often adjusted to the range of four to eight years.

The FD method is not appropriate for the analysis of the micro–macro relation because the FD series has negative values. In addition, its relative deviation is larger than one, due to the noise-amplification inherent in first differencing. Therefore, the FD reference is not proper for studying micro–macro relation.

For the US real GDP quarterly data, the average relative deviations implied by the three detrending methods plus the method assuming stationary (ST) are given in Table 13.1; the relative deviations under the HP method in different sub-periods are given in Table 13.2. The average relative deviations of other macroeconomic indicators in 1980s using the ST and the HP methods are given in Table 13.3.

From Table 13.1, we see that the HP trend produce the smallest relative deviation and the largest implied number from empirical data, which is closer to the empirical numbers of economic agents described in section 13.3.2. Therefore, we take the HP trend as our standard reference, and use the ST method as the upper bound for the relative deviation for macroeconomic indicators. The choice

Table 13.1 The relative deviation and implied number of degrees of freedom for GDPQ using four detrending methods

Data	*GDPQLn(HP)*	*GDPQLn(LL)*	*GDPQLn(ST)*	*GDPQLn(FD)*
Ω (%)	0.2	0.4	1.2	140
N*	200,000	70,000	7000	0.5

Notes
Here, the logarithmic GDPQ data is averaged over the period 1947–1995 with a moving time window of ten years. The implied numbers of degrees of freedom are rounded to one significant figure.

Table 13.2 The relative deviation and implied number of degrees of freedom of GDPQ (HP) in different sub-periods

Data	*1952*	*1960*	*1970*	*1980*	*1990*	*Mean* (ρ)
Ω (%)	0.31	0.15	0.23	0.24	0.13	0.21
N*	100,000	400,000	200,000	200,000	600,000	200,000

Table 13.3 The relative deviation and implied number of degrees of freedom for several macro indexes under ST and HP methods

Ω (%) [N]*	*GDPQLn*	*GCQLn*	*GPIQLn*	*LBMNULn*
ST	1.2 [7000]	1.4 [6000]	2.2 [2000]	1.1 [8000]
HP	0.22 [200,000]	0.16 [400,000]	1.3 [6000]	0.43 [50,000]

Notes
Here GDPQ is the US real gross domestic product in 1987 US dollars, GCQ is the real total consumption, GPIQ the real domestic investment, and LBMNU the hours of non-farm business. The data source is Citibank. The estimates of relative deviations are averages over the period between 1947 and 1995 with a moving time window of ten years.

of logarithmic GDPQ data is consistent with the econometric practice, which typically uses the logarithm of a macro series in analyzing business cycles.

From Figure 13.2 and Table 13.2, we see that the relative deviation of the HP series is slowly changing over time with a long period of about 25 years, from high of 0.3 percent during the Korea war in the early 1950s to a low of 0.1 percent in early 1990s. Its implied number of degrees of freedom lies between 100,000 and 600,000 in all sub-periods. There is no explosive tendency in the relative deviation. If we ignore the long-wave of the relative deviation, the linear birth–death model for exponential growth appears to be a first approximation for macroeconomic movements in the real GDP. Its implied number of degrees of freedom on average is about 200,000.

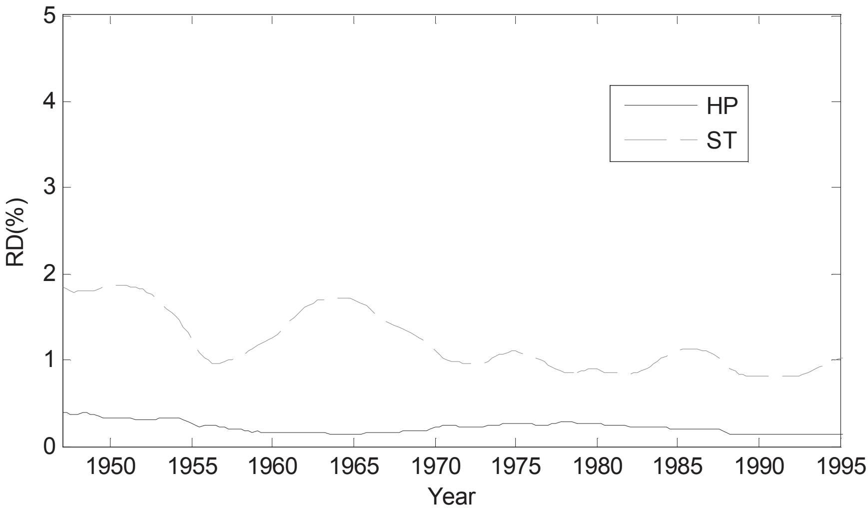

Figure 13.2 The relative deviations of GDPQ under the HP and ST references.

Notes
The solid curve is the relative deviation under the HP reference; the dashed curve is under the ST. The width of moving time window is ten years. Reflective boundaries are added at both ends.

Let us examine the HP results in Table 13.3. First, there is no evidence of $N = 1$, which is implied by the representative agent model. Second, the relative deviation of consumption is slightly less than that of GDP; but non-farm business hours and investment are much more volatile. Third, our measurement of the relative deviation reveals more information about the microstructure of the US economy than those papers in the RBC literature which measure the standard deviation of the HP cyclic components alone, without a comparison to the HP trend components (see, for instance, Kydland and Prescott 1990). We will see this point in the following discussion.

13.3.2 Potential sources of business cycles

In Table 13.3, the relative deviations with HP detrending are roughly in a same order. The magnitude of their relative deviation is from 0.2 to 1.3 percent; its implied number of degrees of freedom ranges from 6000 to about half a million. Can we associate these estimates with actual numbers observed in the US economy? According to the US Bureau of Census in 1980, the US civilian labor force was 106.9 million, the relevant implied numbers and the potential relative deviations are given in Table 13.4.

From Table 13.3 and Table 13.4, we can see that the actual relative deviation for the real GDP and non-farm business hours is 20 to 40 times larger than the potential relative deviation that could be generated by households; correspondingly, the implied number of degrees of freedom estimated from real GDP and non-farm business hours are 400 to 2000 times less than the actual number of households. We can conclude that fluctuations at the household level are not capable of explaining the large observed relative deviations in real output and business hours. There is from this point of view little empirical evidence to support Lucas' theory, which tries to explain persistent unemployment, such as during the Great Depression, as a reflection of voluntary choices of workers.

The implied numbers of degrees of freedom for non-farm business hours and real consumption are about 50,000 and half a million respectively. These figures suggest that it would be better to consider business organizations, such as labor unions and chain stores, rather than individual households and firms, as the basic subsystems or clusters driving fluctuations in modern market economies.

Table 13.4 Numbers of households and firms in 1980 of the US economy and corresponding potential relative deviations

Micro-agents	*Households*	*Corporations**	*Public companies*
N	80.7 million	2.9 million	20,000
Ω* (%)	0.01	0.05	0.7

Source: the US Bureau of Census.

Note

* Here, we count only those corporations with more than $100,000 in assets.

The potential relative deviation in real output and investment generated by the actual number of corporations in the US economy is four to 30 times smaller than the observed relative deviation. Correspondingly, the implied numbers of degrees of freedom for fluctuations in real GDP and investment are 20 to 500 times smaller than the actual number of firms. This is a clue that large firms dominate at the micro level. There is weak evidence for the equilibrium picture of perfect competition at the firm level from macroeconomic data.

In the financial market, the potential relative deviation induced by the actual number of public companies is about half of the observed relative deviation in investment, while the implied number of degrees of freedom from real investment fluctuations is roughly the same as the number of financial companies. This constitutes some evidence that fluctuations in the financial market have a much stronger impact than those in the labor or producer market in generating business cycles.

13.4 Fundamental issues in microfoundations approach and rational expectations

In this section, we will discuss some fundamental issues concerning the statistical nature of micro–macro relationship within the equilibrium framework.

13.4.1 Essential difference between one-body and many-body problems

The representative agent model in the RBC literature is explicitly an one-agent model. So $N = 1$, which is equivalent to assuming that all underlying microeconomic variables are perfectly correlated. This is drastically erroneous with the findings in Table 13.1.

A genuine model of a micro–macro relation should consider the statistical properties of a sum of elements. The LMI model appears at first to be a model with many agents but closer inspection reveals that it is a representative agent model in disguise. On the surface, the LMI posits N young producers and N old consumers in an overlapping generation framework in each time period. However, Lucas solves the optimization problem only for a representative agent, since he calculates the optimal consumption and labor supply not for each individual, but only for an average (expressed in per capita terms). The large number N in the Lucas model is an arbitrary parameter without economic consequences, which can be normalized to one as in the case of the indivisible labor model (Hansen 1985).

To our knowledge, the microfoundations approach has not yet developed a full-fledged micro–macro model with many agents.

13.4.2 The statistical nature of economic information and market diversity

In the general equilibrium literature in microeconomics, all the agents engage in exchange with each other in a decentralized market. Therefore, price variation should be represented by a probability distribution. Even if all the agents within a homogeneous group have the same expectation, i.e., they agree on the mean value of future prices, the variance of actual exchange prices could not be zero in their exchange activities (McKenzie 1987). The diversity of people's behavior is rooted in the degree of individual freedom, which is the essence of a decentralized market.

Strange as it might seem, the LMI model represents a centralized market without any freedom of individual choice. Its basic setting is quite simple: exchanges occur at two separate markets in order to introduce a fluctuation in relative price. The young households are allocated stochastically, a fraction ϕ going to market A and fraction $(1 - \phi)$ going to market B.[4] Each young household supplies n units of labor and produces n units of real output. Here, the individual choice of n is determined by the allocation variable ϕ and money growth rate χ; the price is a unique function of three systematic random variables: ϕ, χ, and m, which is the pre-transfer money supply to old consumers. In other words, the exchange price and individual labor supply of $2N$ agents at each period are completely controlled by three systematic shocks at the macro level. No degrees of freedom are introduced to represent variation at the individual level in the LMI model.

The function of a centralized market is apparent in the determination of aggregate output (and employment) in the LMI model. The possible states of individual output are only two (the number of separate markets) not N (the total number of young households). We can see this from Lucas' equation (13.6). (Lucas' original numbers to label the equations in the LMI model is equation 28.)

$$Y_t = N\left\{\varphi_t\, n\left(\frac{\chi_t}{\varphi_t}\right) + (1-\varphi_t)\, n\left(\frac{\chi_t}{1-\varphi_t}\right)\right\} \tag{13.6}$$

The meaning of equation (13.6) is straightforward. The total number of workers is N. Exchanges occur at two separate markets. There are $N\phi$ young producers at market A and $N(1 - \phi)$ at market B. At each period t, the labor supply in each market is uniquely determined by

$$n\left(\frac{\chi_t}{\varphi_t}\right) \text{ and } n\left(\frac{\chi_t}{1-\varphi_t}\right),$$

respectively. That is why the total output in market A is the total producer number $N\phi$ times the average output $n(\chi, \phi)$, not a summation over n as in equation (13.3) and equation (13.4). From the point of view of statistical mechanics, equation (13.6) has the incredible implication that the behavior of all economic agents in each market is perfectly correlated, exactly as in the RBC case!

More accurately speaking, the effective number in the LMI model is two, because market A and B behave like two robot armies of consumers. Lucas deliberately chose this number, since the relative deviation for a two-point distribution is largest (= 1) among all possible distributions for a positive variable, as we pointed in section 13.2.1. However, implied numbers from empirical macro data are much larger than two.

13.4.3 Intertemporal substitution, relative price movements, and arbitrage opportunities

How could the independent agents end up with a perfectly correlated behavior in each market like a robot army? The device proposed in the LMI model to achieve this magical result is the rational expectations hypothesis.

Lucas has described his picture of rational expectations in his introduction to *Studies in Business-Cycle Theory* (1981):

> It became clear to me why Phelps had imagined an island economy, with traders scattered and short on useful, system wide information. It is exactly this feature that permits all producers *simultaneously* to believe they have gained relative to others as the consequence of a monetary shock.

Lucas believed that the rational expectations mechanism could amplify price fluctuations by inducing the same beliefs and hence the same behavior in many people simultaneously. Muth, the originator of the rational expectations concept, on the other hand, thought rational expectations would reduce price fluctuations through arbitrage (1961).

> Speculation with moderately well-informed price expectations reduces the variance of prices by spreading the effect of a market disturbance over several time periods, thereby allowing shocks partially to cancel one another out. Speculation is profitable, although no speculative opportunities remain.

We can see that the conflicting perceptions of rational expectations of Muth and Lucas raise a series of open questions on directions of relative price movements and the behavior of independent rational agents.

One critical question is how there could be any arbitrage opportunities when the great majority of economic agents in one market take the same orchestrated action as envisioned by the LMI model. Arbitrage is possible when the market is decentralized and commodity exchanges occur at different prices. We will argue that individual variability in transaction prices and arbitrage possibilities cannot be excluded from a market when the appropriate statistical framework is introduced into the LMI model.

Consider a simple scenario starting with a random shock in money supply or technology, which generates a systematic shock in output prices and wages. (Note that since the LMI model does not envision any price difference between labor and output – no profit motivation exists for producers in the model.)

Choose one of the two markets, say, market A. There are $N\phi_t$ identical agents having same rational expectations after a shock so that they all believe the current average wage is below the natural rate, and the future average price and average wage will rise to equilibrium in the next period (25 years later!).

Now we want to ask whether all these identical agents would make the same responses even if they share the same information (whether the information is "perfect" or "imperfect"). Our answer is NO if these rational agents are not price slaves but price setters in a general equilibrium market.

First, the labor or output price must be varied across economic agents. If we assume that the only output is food for human subsistence, then we will conclude that exchange must occur between agents since a cleared market has no inventory for each household. In a decentralized market, there is no mechanism that will lead to uniformity of transaction prices when exchanges occur between scattered agents. Therefore, the market price of labor or output must be a statistical average (with some variance) over the agents in a market. A price distribution with finite mean and non-zero variance would certainly occur when economic agents have unequal wealth and varying needs of leisure. The LMI model with identical agents should be analogous to the ideal gas model in statistical mechanics, in which all particles have the same mass and elasticity but different initial conditions in coordinates and speed. If all particles are assumed to have the same coordinates and speed, the N molecules become a concentrated point mass rather than a gas with $6N$ degrees of freedom. Its failure to consider individual degrees of freedom is a fundamental flaw in the LMI model, which is not, as a result, consistent with the original idea of general equilibrium in a decentralized market.

Second, transaction price variation must create arbitrage opportunities that would offset the intertemporal substitution effect under rational expectations. Let us consider a simple vacation scenario of relative price (wage and vacation price) movements initiated by a macroeconomic shock in the LMI model.

The time scale of the LMI model is a human generation, on the order of, say, 25 years. Suppose the current average wage is below the natural rate, so that all the agents agree that the optimal supply of labor is, say, 40 percent of normal working hours in this period. Can we imagine that *all the agents* would take a *synchronized* vacation during the first 15 years then work at the next ten years as implied by the rational expectation hypothesis? No, the market would not function continuously if household behavior were so uniform. A more reasonable picture is that vacation plans would vary in such a way that the average work ratio over this period is 40 percent. The different time scales between labor contracts and monetary shocks create conflicting movements in relative prices and arbitrage opportunities for utility-maximizing agents.

If economic agents reach an agreement on an expected mean (or rational expectations), can we predict a net outcome (monetary neutrality or not) in relative price movements? The answer depends on certain unspecified structures in the LMI model. Lucas made strong claims concerning relative prices and general equilibrium in his analysis. In practice, Lucas had only one narrow type of relative price in mind, that is, the current and future wage. To achieve his goal of demonstrating monetary neutrality, Lucas abstracts from two important relative price movements in each period: the relative price between work and leisure at the supply-side of producers and the relative price between finished goods (say food) and leisure at the demand-side of consumers. Lucas implicitly assumed that movements in relative prices are not allowed within a period. The price mechanism in the LMI model is neither a partial equilibrium, nor general equilibrium at a single moment in time, but a self-centered intertemporal equilibrium for an individual atom in a market with a time unit of 25 years. This picture is hard to sustain as an explanation of business cycles in market economies.

Let us assume that only M households (M is large and $M < N\phi_t$) take their vacation in the first sub-period, say the first quarter. The large resulting demand shift would drive up the price of leisure goods, like airfare or vacation club prices. The increased cost of leisure would change the incentives of the rest of the households. So, $(N\phi_t - M)$ of the economic agents would have an incentive for inverse substitution by postponing vacation in this sub-period instead. Their arbitrage activities could offset the intertemporal substitution effect of the first group with M agents in the labor market. The net result will reduce or eliminate correlations between outputs among identical agents in market A.

Is there a neutrality of money in this scenario? The answer depends on the power balance of conflicting interests between the rich (who would be first to take their vacation when a recession begins) and the poor (who would be first to take the arbitrage opportunity when the relative price moves). Therefore, the main mechanism driving a decentralized market with an unequal distribution of income is conflicting interests, not common beliefs (Olson 1965).

There is a symmetrical story for the $N(1 - \phi_t)$ agents in market B. In sum, the statistical nature of relative price movements cannot be ignored in a genuine micro–macro model with many independent agents.

13.4.4 Path variability and the Lucas critique

Some readers may contend that the above criticism is beyond the scope of the LMI model. No theoretical model can include every feature in nature. The question is if the theoretical model provides a consistent answer to the question it asked. If we take the LMI model as a starting base, can we reach a consistent explanation of business cycles?

The Lucas critique of conventional econometrics rightly pointed out that "any change in policy will systematically alter the structure of econometric models" (Lucas 1976, 1981). However, a similar critique can also be applied to the microfoundations models in macroeconomic theory: is the LMI model itself immune from Lucas' own critique?

Suppose econometricians could fit a discrete-time model with rational expectations to quarterly data and believe economic agents will use this model to forecast its path for future periods. Then, we will see that any wave in relative price movements and arbitrage activities starting in the current quarter will systematically alter the structure of the econometric model and lead to deviations from the previously forecasted path in the next quarter. In other words, the LMI model suffers from the same flaws the Lucas critique identified in traditional macro econometric models.

Friedman once believed that speculators who based their trading strategy on the belief in the eventual emergence of equilibrium (i.e., rational or negative feedback strategy) always take money away from noise (i.e., irrational or positive feedback strategy) traders (Friedman 1953b). This is not true when arbitrage risk and dynamical complexity exist (see De Long *et al.* 1990; Chen 1999). As the collapse of long-term capital has shown, arbitrage is risky when the future economic trends are unpredictable.

These two factors create a dilemma for the rational expectations research program. The more agents believe in the existence of a natural rate or rational expectations, the more they open up opportunities for arbitrage, and the smaller is the probability of success for maintaining the rational expectation co-movements. In other words, the rational expectations hypothesis is a self-defeating prophecy. Lucas once claimed that government policy was effective only when it was unexpected. Analogously, rational expectations cannot last very long when they mislead its believers!

13.4.5 Multiple time scales, information complexities, and the neutrality of money

The issue of "perfect" versus "imperfect" information is superficial, since there is no operational way to distinguish real from monetary disturbances within a short period. From the discussion in section 13.3.1, there exist multiple relevant economic time scales, which are represented by various detrending methods. In real markets, globalization leads to 24 hour trading in financial markets. Arbitrage activities are conducted in seconds in electronic exchange markets. The Federal Reserve adjusts the base interest rates on a weekly basis. Most macro indicators are published on a monthly or quarterly basis. These multiple time scales raise a fundamental problem for any simple discrete-time model. As Sims pointed out, the average period of a generation is about 20 to 30 years, while the period of the business cycle is in the range of two to ten years, so how can we expect the overlapping generation model to be relevant to business-cycle theory (Sims 1986)?

In a world of economic complexity and multiple time scales, there is no role for the concept of "perfect information" or "all available information" in decision making. In any scientific research, the operational issue is what is the relevant information available to answer a specific empirical question? Specifically, which variables are pertinent in theoretical modeling? What order, say, which moments of statistical data are sufficient in evaluating complexity and uncertainty? The rational expectations school assumes that rational agents will use all available information to form their rational expectations. But in practice, their scope is confined to a narrow band of available data.

Consider the debate over pertinent variables in financial analysis. The fundamental school mainly focuses on price information while the technical school also considers other information on quantity movements and market psychology.

If traders ignored changes in price trends and trading volume as the equilibrium business cycle models assume, there would be no arbitrage activities, nor value-discovering mechanisms in market economies.

The economic market is like a democratic parliament. Even when they have near the same information, economic agents rarely reach a consensus. If Ricardo had proposed his famous thought experiment of doubling all people's money holding as a piece of legislation, he would have had no chance to win a majority vote in the parliament, since the proposal would lead to a regressive subsidy in a democratic but unequal society (Chen 1999).

Mathematically speaking, the rational expectations hypothesis is a simple model based on considering only the first moment of statistics. The LMI model replaces the theoretical price distribution of probability by a two-point distribution while the RBC model uses only one realization of a random trajectory. In financial analysis, second and fourth moments are widely used. In fluid dynamics, up to seventh moments are studied in theory and experiments on turbulence. Is there reason to believe that information in macroeconomics is so much simpler than that in finance and physics?

If we recognize the complex nature of economic dynamics, we may reach a new understanding of the difficulty of understanding monetary neutrality.

First, the relation between money and real economy has no simple pattern under multiple time scales in economic dynamics. Monetary policy has a direct impact only on short-term interest rates but an indirect impact on medium and long-term interest rates.

Second, whether a monetary shock would produce purely monetary or real effects is not a simple question of people's belief in government policy, but a complex problem in the dynamics of economic structure. Lucas once acknowledged, "rational expectations are equivalent to the existence of a natural output rate" (Lucas 1981). In the 1990s, the United States witnessed a period of high growth, low inflation, and a low unemployment rate, which is below the so-called "natural rate" or NAIRU (Galbraith 1997). The debate on NAIRU or monetary neutrality has faded in the "new economy" because changes occurred in economic structure not in academic doctrine.

Finally, the increasing frequency and scale of financial crisis around the world reminds us that financial intermediation plays a more important role than household and firm behavior in generating business cycles and economic crisis.

13.5 Conclusion

Mathematics is not just a tool in economic theory. It is also a discipline in quantitative analysis. The Principle of Large Numbers is a basic constraint in probability theory, statistical mechanics, and models of micro–macro fluctuations.

There is a striking asymmetry in the numbers of workers and organizations. This is the most visible characteristic of an industrial society. The new classical school raised an important question in the study of the relation between micro structure and macro fluctuations. Unfortunately, they did not uncover the main source of business cycles. The microfoundations models often ignore the essential difference between one-body and many-body problems and the statistic nature in modeling micro–macro dynamics. According to the Principle of Large Numbers, there is little hope for a microfoundations model in the labor market, since the relative deviations of aggregate micro fluctuations are much smaller than those observed in macroeconomic indicators. The empirical and theoretical evidence indicates that the macroeconomic system can be better described by a three-level (micro–meso–macro) rather than a two-level (micro–macro) system (Holland 1987). A further study of industrial organizations and financial intermediate may provide a better understanding of the observed magnitude of relative deviations from macro indicators.

Lucas claimed that his 1972 model is a "first" and "rigorously formulated" equilibrium model of business cycles (1981). Lucas made a significant contribution in developing mathematical economics in business-cycle theory. However, Lucas did not develop a quantitative model with probability distributions in prices and outputs, which can explain observed magnitude of business cycles. The harmonious picture of monetary neutrality abstracts away conflicting interests and arbitrage opportunities, which are essential for market competition and pricing mechanism. Theoretically speaking, the LMI model is not consistent with the original idea of general equilibrium with many goods, many agents, and interdependent changes in relative prices. The fundamental issue of economic complexity (including multiple time scales, structural variability, nonlinear interaction, and dynamic uncertainty) cannot be ignored in business-cycle theory. Although we mainly discuss the LMI model in this chapter, readers may consider similar problems in other equilibrium models of microfoundations and rational expectations. From our analysis, the linear equilibrium framework so far has not provided a consistent framework for business-cycle theory (Chen 1999).

If the new classical school did not shed much light on business-cycle theory, can we draw some valuable lessons from their idealistic efforts? From our observation of large differences between the implied numbers from macro fluctuations and the actual numbers of economic agents and firms in the US economy, there are three possible alternatives for business-cycle theory: nonlinear economic dynamics at the macro level (Chen 1996b); structural analysis of financial intermediate and economic institution; and macro foundations for micro behavior. We will discuss these approaches elsewhere.

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14 Complexity of transaction costs and evolution of corporate governance[1]

14.1 Introduction

Corporate governance is a complex issue with multi-dimensional goals. Both opportunities and problems may vary with the emergence of separation of ownership and control in large corporations at different stages. Corporate governance involves many parties including owners, managers, workers, suppliers, creditors, communities, and regulators with different interests. Obviously, corporate governance is a typical field of political economy, where changing market and the power balance will shape an evolving organization. It would be very difficult to identify simple rules between governance structure and economic performance. However, financial economics based on the optimization approach has made a series of claims in corporate governance. Their arguments are mainly based on two influential theories in new institutional economics: the transaction costs approach and the property rights theory (Coase 1937, 1960; Alchian and Demsetz 1973). In fact, these two approaches have raised more problems than solutions in equilibrium thinking of firm and institution. Conflicting ideas among Coase theory, property rights school, and agency theory in financial economics (Fama and Jensen 1983) reveal limitations of equilibrium thinking and the potential for an evolutionary perspective in dealing with economic complexity. Methodologically speaking, the concept of transaction costs and its variation of agency costs is a static approach in closed economies without innovation competition, while an evolutionary perspective is a dynamic approach in open economies with innovation and changes. The emerging science of complexity provides new analytical tools for evolutionary economics in studying economic complexity.

In this chapter, we will address corporate governance from the following aspects: first, unsolved issues in corporate governance and basic problems in the transaction costs approach and property rights theory; second, fundamental flaws in Coase theory of zero-transaction costs; third, diversified experiences in corporate governance, especially China's experiments in economic transition; fourth, the alternative life cycle theory of changing property rights based on an evolutionary perspective.

We will see that the top-down approach of control and monitor may have negative effect on the competitiveness of the firm. The mechanic picture of transaction costs or agency costs is rooted in reductionism of firm theory. The Coase world of zero-transaction costs is contrary to the law of thermodynamics and historical trends in industrial economies. Diversified patterns in corporate governance and corporate culture can be better explained by the creative nature of the firm in an evolutionary perspective. The survival of a firm is more associated with the emergence of selective mechanisms and adapting ability.

14.2 Unsolved issues in corporate governance

The issue of corporate governance has two dimensions. One is political and the other is economic. In the case of diversified ownership, how to divide the pie or so-called profit among shareholders and stakeholders is a political issue in power balance and the rule of the game. We may leave this issue to political economy. Our discussion will mainly focus on the economic dimension: what can we learn about corporate governance from competing economic perspectives?

In the Preamble of *OECD Principles of Corporate Governance*, it said (2004):

> Corporate governance is a key element in improving economic efficiency and growth as well as enhancing investor confidence.... Good corporate governance should provide proper incentives for the board and management to pursue objectives that are in the interests of the company and its shareholders and should facilitate effective monitoring.... As a result, the cost of capital is lower and firms are encouraged to use resources more efficiently thereby underpinning growth.... The corporate governance framework should promote transparent and efficient markets, be consistent with the rule of law and clearly articulate the division of responsibilities among different supervisory, regulatory and enforcement authorities.

OECD Principles certainly made a great effort to improve access to the international capital market. However, there is no solid foundation in theory and practice for its claim of "improving economic efficiency and growth." In fact, their real motive was "enhancing investor confidence," especially for foreign investors. There are some issues related to questions of efficiency and growth in economic theory.

First, financial economics so far has no objective measurement of market efficiency. According to the efficient market hypothesis (EMH) in finance theory, market efficiency could be judged by its unpredictability if stock markets are dominated by Brownian motion (Fama 1970, 1991). However, EMH was challenged by our discovery of color chaos, which accounts for about 70 percent of market fluctuations (Chen 1996a). It is also found that there are weak microfoundations for business cycles. The major source of market fluctuations is neither from consumers nor producers, but from financial intermediates (Chen 2002). There were a series of financial crises, such as the stock market crash in 1987, the Asian financial crisis in 1997, and the Internet Bubble in 2002. Some economists emphasize an internal mechanism caused by a positive feedback trading strategy and corruption (De Long *et al.* 1990), while others are concerned with external shocks such as an international speculative flow. Clearly, the financial market is the most complex and regulated market with huge transaction costs and uncertainty, a counter case to the Coase world of zero-transaction costs.

Second, there is no consensus on which model of market institution is optimal and whether there is a historical trend in institutional convergence (Hall and Soskice 2001). It is known that American firms are often overpriced while German and Japanese firms are underpriced in the financial market. At the macro level, the United States has persistent trade and budget deficits while Germany and Japan have persistent trade surpluses. Over-consumption and under-saving in the US can be partially contributed to financial innovation in credit expansion and American power in the global financial market. The Anglo-Saxon model of liberal economics emphasized the shareholder's value while Germany, Japan and Scandinavian models put more weight on shared interests of stakeholders.

Third, there is no optimal choice of economic efficiency even at the firm level. Beauty is in the eyes of the beholder. Maximizing profit or minimizing costs is more complicated in practice than in theory. For a visionary corporate founder, seeking the status of an industry leader in innovations and products would be his long-term goal, while small shareholders would like higher dividends or returns in medium or even short terms. Managers may manipulate the financial outlook to increase their stock options or social status, but workers may care more about job security and social welfare. The property rights theory implicitly favors single or large shareholders for corporate control. The contrary policy of protecting minority shareholders is also relevant for increasing confidence in the financial market (Shleifer and Vishny 1997).

Fourth, the appeal of a transparent market ignores fundamental issues of information ambiguity and economic complexity. Market transparency is meaningful only for cooperative games with symmetric information without economic complexity. A non-cooperative game will stimulate motivation for creating false information or protecting strategic information in market competition. Under constant business-cycle movements, both information diffusion and information distortion may amplify market sentiment and market instability. The recent collapse of Enron and the sub-prime credit market are good examples of information game and information ambiguity under an ill-regulated financial market. Therefore, the benefits and costs of the so-called transparent market depend on the selective rule (transparent to whom and for whose benefit) of the market institution, which is not equal to all players.

Fifth, the relation between growth and globalization of the financial market is poorly understood. People are puzzled about the real cause of the Asian financial crisis. Some Western observers blamed Asian cronyism and nepotism, which is an issue in corporate governance. However, more economists realized the danger of excess speculation and foreign power enhanced by the IMF policy on financial liberalization. Korea opened its financial market under IMF pressure during the crisis. Foreign stock ownership rose dramatically, including foreign shares of top Korean companies. Clearly, the issue here is not only about economic efficiency, but also a fair international order.

Sixth, corporate governance may have a negative impact on corporate culture and strong leadership. Excess monitoring may destroy mutual trusts within the firm. Short-term efforts of reducing agency costs may end up with long-term effects of increasing coordination costs and weakening leadership.

From the above discussion, we can see corporate governance is an important issue in increasing investor confidence under financial globalization, but less clear to its relation with efficiency and growth. To improve our understanding, we need to examine further theoretical foundations in firm theory and organizational development, notably, the transaction costs approach and the property rights theory.

Both property rights theory and theory of agency costs are strongly influenced by the concept of transaction costs (Alchian and Demsetz 1973; Fama and Jensen 1983). Their minor difference is mainly the level and forms of transaction costs inside the firm (Jensen and Meckling 1976). Coase believes that transaction costs are insignificant in the real world (Coase 2004), so that the roles of regulation and governments should be minimized, while property rights school concerns impacts of large transaction costs and the important role of legal institution. However, their common ground is the same one-sided view of transaction costs based on cost competition without innovation competition in a closed economy. We will address their fundamental flaws in evolutionary dynamics in open economy.

14.3 Fundamental problems in the Coase approach of transaction costs

Coase raised a fundamental question of why firms exist in an exchanged economy (Coase 1937). Williamson found some interesting mechanisms related to vertical integration (1979). A firm is an organization embedded in industrial structures with many layers. At least three levels are related to the existence of the firm: market and environment at the macro level above the firm, production units and individuals at the micro level below the firm. However, Coase had neither interest in market and society as Adam Smith and Karl Marx did, nor industrial structure like Chandler studied (Chandler 1992). Coase put transaction costs as the basic unit in analyzing economic organizations.

The Coase approach is similar to the Ostwald theory of energism in late nineteenth century physics. It considered energy transform rather than matter structure (consisting with atoms and molecules) as the fundamental framework in understanding universe (Holt 1970). Ostwald finally gave up his theory after experiments proved the existence of molecules based on Einstein's theory of Brownian motion. The Coase theory is an extreme approach of reductionism, which has no sense of economic complexity and time history. This is the root of all shortcomings in costs-based equilibrium thinking. There are several problems for the transaction costs approach.

First, the issue of firm size is an ecological issue related to three levels, not a static issue of one level. For Coase, the size of the firm is purely determined by internal balance between transaction costs and coordination costs, while both the competitor's behavior and market size have no impact to the firm. This is a simple-minded and self-centered theory contrary to common sense. It is known in biology that the largest animal living in the oceans (blue whale) is larger than the largest animal on land (elephant) because of their difference in resource limitation (Schmidt-Nielsen 1984; O'Neill 1989). For the same reason, multinational companies today are much larger than the British firms in early industrial revolution. The well-known Smith theorem states that division of labor is limited by market extent (Stigler 1951). Predators face survival pressure of matching their size or skill to their rivals, so do competitive firms. Variation in organizational size and behavior can be understood by the trade-off between stability and complexity in dynamical systems (May 1974a; Chen 2005). In contrast, the inward view of transaction costs only concerns frictions in a market economy, which originated from a mechanical framework in classical economics. Therefore, the transaction costs approach cannot address living features in a market economy, such as large variations in corporation sizes and changing waves of merges and spin-offs. Coase and Williamson claim that a monopoly industry is efficient and competitive. Recent experience shows that even the traditional automobile industry is sourcing out their parts suppliers under intensified innovation competition. Contrary to Williamson's argument, Dell and Lenovo could beat IBM and other giants with vertical integration in the computer industry, mainly because these innovative companies have more flexibility in adapting to rapidly changing technology. In a limited market with innovative competitors, transaction cost is not a decisive factor. Corporate strategy and corporate culture may be more important than governance structure for corporate survival. Methodologically speaking, the resource-based firm theory is more realistic in modern industry (Penrose 1959). In contrast, the Coase theory of the firm is a self-centered thinking without market environment and competitor challenge.

Second, Coase ignores two-way movements of transaction costs in firm competition, which is contrary to the one-sided view of costs-based reasoning. For a mature market without rapid growth or technology changes, reducing transaction costs by means of direct selling or vertical integration may be a good strategy. However, under an emerging market with fast growth and rapid innovation, increasing advertising or spin-off non-core parts can be a winning strategy even at the cost of increasing transaction costs. Similarly, the agency theory has the same problem when they ignore the positive side of separation of ownership and control under an increasing division of labor. Therefore, cost factor may be an important but not critical for an open economy with the rise and fall of firms. Price/cost competition plays a dominate role in neo-classical economics and transaction costs approach, which is only relevant to a traditional market without product innovations (Schumpeter 1934; Chandler 1992). A physician would not judge the sickness of a patient only by measuring his excretion without first examining his physical function and structural conditions.

Third, Coase has no historical picture of increasing division of labor and expanding market in industrialization. When extending a market for existing products, transportation and communication costs must increase compared to local markets. Transaction costs are always larger than zero under the law of physics, even though technology progress may reduce unit transaction costs per action. Market expansion and technology innovation has a historical trend of increasing energy consumption along with increasing complexity of division of labor, which is visible from global warming during industrialization. In the marketing game, there exist large amounts of image distortion, information misconception, and information noise. Without market regulation, market competition could become a vicious game. There was a solid evidence of increasing transaction costs in the United States, which was about 15 percent in 1870 to more than 50 percent in 1970 (Wallis and North 1986). Therefore, the Coase illusion of reducing transaction costs by market competition without regulation has no empirical ground in industrial history.

Fourth, the Coasian world of zero-transaction costs is contrary to basic laws in physics. Coase theorem claims institutional changes would converge to an optimal system regardless of initial conditions (Coase 1960). His argument was based on a false analogy of a frictionless world in physics (Coase 1990). Inertial movement with zero-friction is a scientific theory with good approximation for planet motion, which is verified by thousands of launches of artificial satellites. But zero-transaction costs do not exist in the real world since minimum energy costs associated with information transmission is larger than zero according to the uncertainty principle in quantum mechanics (Brillouin 1962). The Coase belief of reducing transaction costs in market economy is also contrary to the second law of thermodynamics. The emergence of life and social organization is a nonequilibrium process (Prigogine and Stengers 1984). Transaction costs are a disorganized form of energy, which is similar to heat or entropy in physics. The increasing complexity of an industrial society is associated with increasing consumption in energy and raw materials, which implies increasing entropy production. The equilibrium trend of convergence implies heat death in an isolated system, but a nonequilibrium trend of diversity is driven by evolutionary thermodynamics in open systems. In this sense, the Coasian world of zero-transaction costs is essentially a perpetual motion machine in the form of a heat engine without temperature difference and heat dissipation.

Fifth, Coase did not solve the issue of firm boundaries even from an equilibrium perspective (Holmström and Roberts 1998). From the view of evolutionary thermodynamics and complexity science, the emergence of a firm is similar to the origin of life, which is characterized by the emergence of selective boundaries. The role of Maxwell's demon is crucial for life's persistence, i.e., nonequilibrium order created by matter flow, energy flow, and information flow (Prigogine and Stengers 1984).

In sum, the Coase theory of transaction costs and its variation of agency costs only catch partial static elements but lose the whole dynamic picture of the firm. The inward looking perspective of the firm is rooted in a negative view of human nature under a non-cooperative game and reductionism in firm structure. There is no room in equilibrium economics for entrepreneurship, innovation, strategy, and corporate culture. Coase once criticized the mainstream economics as "consumers without humanity, firms without organization, and even exchange without markets" (1990, p. 3). To paraphrase Coase, the transaction costs approach still presents an artificial picture of consumer without curiosity, firms without complexity, and markets without evolution (Nelson and Winter 1982; Cyert and March 1992; Chen 2007b). We need a better perspective in understanding diversified patterns in corporate governance.

14.4 China's experiences in corporate governance

In the early 1990s, Alan Blinder made an interesting observation (1990):

> Much has been written about Japan's formidable challenge to American industrial preeminence. But the amazing Japanese economy poses another challenge – one that has barely been noticed. I refer to Japan's challenge to received economic doctrine. Stated briefly and far too boldly, the Japanese have succeeded by doing everything wrong (according to standard economic theory).... Studying the Japanese economy has led me to a tentative conclusion: that market capitalism, Japanese style, departs so much from conventional Western economic thought that it deserves to be considered a different system. (For example, Japanese put producer ahead of consumer and nation-building ahead of profits for share holders. Japanese managers are mainly motivated by long-run goals rather than short-run profits driven by stock prices. Japanese firms are more cooperative in development and research. Japanese foreign trade is not free but managed open. Salary differentials are much less and workers are more stable than American.)

Certainly, the confidence in the Japanese model of corporate governance was weakened during ten years of stagnation in Japan. American style corporate governance was introduced into Japan in the 1990s. After a decade of experiment, only 2 percent of Japanese listed companies adopted the American model of board of directors, while the average number of outside directors per Japanese company is only 0.8. At the same time, rebuilt cross-shareholdings with friendly companies and other measures are developed to counter the rising threat of American style hostile takeovers. Many Japanese firms consider corporate culture rather than corporate governance as the main strength in global competition (Hirota 2007). With the Japanese experience in mind, we will discuss China's recent experiments during transition and see what we can learn from the study of corporate governance.

China experimented with all kinds of governance models before and after the Reform, including a Soviet type of centralized command economy mainly in the defense industry, co-op type state owned enterprises (SOEs) and collectives that had small wage differentials between managers and workers, the Yugoslavia model of worker's participation in management, the Hungarian model of profit sharing, the American model of worker flexibility (lay-off workers with little constraints), and managerial incentive including stock option. Coase theory and the theory of property rights became influential in China's reform. One notable application was promoting a "clear delineation of property rights" in SOE reform, which paved the way for encouraging an incentive mechanism under mixed property rights including public, collective, private, and foreign ownership. Surprisingly, all models worked in some aspects or some stages, including the home-grown model of the family contract system, but no single model works all the time and all the regions. Several factors impose significant constraints to governance patterns and organizational forms.

First, large population pressure puts job creation for surplus labor ahead of the efficiency target as a primary goal both in urban and rural reform. This is an ecological constraint in nature to corporate governance. Achieving economic efficiency by large-scale lay-offs is the least acceptable option during economic transition. This is the base of the so-called soft-budget constraints (Kornai 1986), which still widely exists for privatized firms in China, East Europe and the former Soviet Union (EEFSU).

Second, huge regional differentiation sets a severe limit to any centralized policies or unified legal regulations. This situation leaves little space for a Western type rule of law but a lot of room for strong leadership in local governments and firms originated from SOEs and collectives, even though these leaders have no clearly defined controlling ownership.

Third, the increasing complexity of economic scale and scope leads to diversified patterns co-existing in corporate governance and property rights. No single pattern can dominate all industries. For example, family companies succeed in small farms and small firms with simple technology, but collective farms and TVEs (township and village enterprises) are more competitive in middle-size farms and factories because of a scale economy. For large automobile firms with advanced technology, both SOEs and joint-stock companies have comparative advantages in human resource, advanced technology, and financial sources. Here, ownership structure may not be a critical factor or uniform pattern under global competition.

Many American business models were introduced and tested in China's decentralized experiments and market transition. Positive advances were made with certain limitations. First, breaking state monopoly in the airline and telecommunication industries was an effective policy for advancing competitiveness, but the proper intensity of competition is still an open issue because of network effect and scale economy. Second, productivity was first improved by increasing labor flexibility (i.e., breaking the so-called iron rice bowl or life-time employment); however, a high turnover rate in manufacture industries became a new problem for competitiveness. Many firms reconsider the German and Japan model to attract highly skilled workers. Third, introducing independent board directors may have a good public image for state firms, but have few impacts for new publicly listed companies since their management position has little correlation with stock price performance. Fourth, MBO (manager buy-out) in SOE restructuring works for small and medium-sized SOEs, but faces strong resistance for large SOEs because of public dissent. Clearly, corporate governance is not a simple issue of stock performance in the financial market, but a multi-dimensional issue including ecological, cultural, social, and political constraints.

China's learning and experiments in corporate governance provided some new lessons for property rights and corporate governance. The rise of TVEs in the 1990s surprised orthodox economists, since TVEs had little access to skilled talents, advanced technology, raw materials, market channels, and bank credit. Its competitive advantage lies in low-cost labor insurance based on collective land and flexibility in marketing strategy. Local governments played an active role in credit enhancing, since newly started TVEs often had little collateral, credit history, and venture capital, but local officials may have better private information on the ability of TVE leadership.

The rise of global competitive firms is also puzzling, since more advanced firms in EEFSU were either taken over by multi-national giants or simply closed. China's emerging companies are characterized by strong leadership and corporate culture, with varied ownership structure and corporate governance. Notable examples are: Changhong Co. transformed from a military radar company into a color TV firm. Haerbin Airplane was a SOE jumping into the automobile business. Lenovo was a spin-off company from the non-profit Chinese Academy of Sciences and later bought the IBM PC division. Haier was a collective firm near bankruptcy in 1980s, and then emerged in the home appliance market. Geely automobile is a private company started by a TVE entrepreneur. Chery automobile was founded by a middle-sized city government in a poor province. Their rapid rise is characterized by (American type) strong leadership combined with (Japanese type) corporate culture. Their common goal was not maximizing shareholder value but industry competitiveness. Their fast progress is not based on owner's control of management, but motivation of fellow managers and workers with shared value and benefits.

The late Chicago financial economist Merton Miller once made a sharp observation when he addressed a Shanghai Symposium on China's SOE reform (Miller 1995):

> The issue of property rights is certainly important. However, there is no optimal solution for property rights system. The Anglo-Saxon model is characterized by short-term behavior and insufficient investment while the German–Japan model is long-term behavior and over investment.

It is known by the MM theorem that corporate value is independent of the debt structure under perfect competition (Modigliani and Miller 1958). It also implies that the corporate value has little correlation with ownership structure. Our observations on China's experiment seem to support Miller's argument rather than the property rights school.

Careful readers may notice that both the MM theorem and the theory of property rights have common ground of equilibrium perspective. Why do they differ sharply in the issue of corporate governance? Obviously, linear approximations are resulted from segments of a nonlinear curve. Nonequilibrium phenomena may use equilibrium approximations under certain conditions. The question is: which approximation can better explain empirical evidence? Both the Coase theory of the firm and the theory of property rights are normative theories in nature, since transaction costs and agency costs are hard to define and measure. The condition for the MM theorem is no arbitrage opportunity or linear pricing in competitive financial markets. Whether or not a nonlinear pricing (i.e., deviation from perfect competition) plays a major role in market is an empirical issue. In this regard, the MM theorem has more analytical power than the transaction costs approach in understanding the complex nature of corporate governance.

The central idea of corporate governance is a top-down commanding approach in corporate management and control. It soon discovered that financial incentive alone cannot buy loyalty and cooperation from managers and workers. Two Chinese characters have dominated political and business culture in history: leadership and brotherhood, which is a sharp contrast to Western style competition based on individualism and rule-based game. Traditional Confucius value is more compatible with cooperative competition. Therefore, putting the stakeholder value ahead of the shareholder is essential for corporate survival in China's competitive market.

Western observers may consider the large bad loans of state banks as the main evidence of inefficiency of state ownership or corruption of political system. In fact, China's state banks are not traditional commerce banks at all. In some degree, they also provide large low-interest bank loans to start-up firms at an early stage of Reform, without condition of high-returns as venture capital in Western style. The typical success rate was less than 10 percent for Western venture capital. The average bad loans for the state banks were about 30 percent in China. Judging from China's 10 percent growth rate in the past 30 years without a financial crisis, we can fairly say that China's state banks act like state insurance for creative destruction in technology replacement. China's rapid growth and smooth transition has achieved under mixed property rights, while EEFSU suffered from severe depression, whose output declined more than 40 percent in ten years (Chen 2006). In the recent boom of China's stock market, the market value of three big state banks is comparable with leading American private banks. This fact indicates that financial investors have higher valuation of China's economic performance than mainstream economists. Clearly, market size and growth prospect (not downsize and recession under premature property rights system in EEFSU) play more important roles in raising China's corporate value.

Based on the above observations, we may develop an alternative theory of evolving property rights in the next section.

14.5 Life cycle theory of firm development and symmetry breaking in social evolution

Marshall pointed out that economics should be more like biology rather than mechanics (Marshall 1920). Consider firms like animals: they have their distinctive lives from infant to old age and death. We may develop a life cycle model of organization changes. Our observation is both empirical and historical. A brief outline is the following.

First, the creation and survival of a firm mainly depends on its ability to create value, not reduce transaction costs. Schumpeter had more insight in firm evolution. The origin of a firm implies symmetry breaking in time and space, which is an irreversible process under nonequilibrium process while the Coase theorem implies symmetry between consumption and investment (Chen 2007b; Cheung 1998).

Second, the precondition of the existence of a firm is the emergence of selective boundaries, which could absorb useful resources and release useless waste. Further differentiation of structure is aimed at adapting to the local environment in its market niche. The selective role of Maxwell's demon can be realized by management and leadership (Maxwell 1872; Prigogine and Stengers 1984; Lef and Rex 1991). Ultimately, it is the selective mechanism (not cost structure), which is responsible for a firm's creativity and competitiveness. Contract design is asymmetric for corporate governance and incentive mechanism, mainly for securing company goals but less for worker's protection.

Third, firm's ownership structure or property right is changing at different stages during its life cycle.

Newly started firms may have visionary dreams, but little human and financial resource. Their initial capital mainly comes from family, friends, or even "fools." Idealism, brotherhood, and collective efforts help the small dream grow under tremendous uncertainty. Few private venture capitalists would dare to support such a dream at the initial stage. Therefore, technology transfer from non-profit universities and financial help from state would be crucial for research and development at the early stages, which is visible from the land-grant universities in the US. Accordingly, new firms often start without a clear delineation of property rights. Initial capital with soft-budget constraints is common in emerging markets with unknown risk.

Things change during the second stage of take-off. Various ownership structures, such as partnership, cooperative, private, or stock-holding companies, are developing for the firm's expansion. The choice of organizational form depends on the industry features including technology complexity, the scale of fixed investment, and changing market conditions.

With few competitors and more or less stable technology, vertical integration may be effective for risk management. For industries with many competitors and rapidly changing technology, it would be better to spin off non-essential business and concentrate on core business. Even at a mature stage, calculation of transaction costs is hard to judge compared to other concerns such as risk control and incentive mechanisms (Cheung 1969). Strategic decision making is hardly based on transaction costs alone.

For a money-losing or dying industry, soft-budget constraints may appear again, since it is hard to decide whether to cut losses or try a second chance. In this regard, indiscriminative credit tightening under the doctrine of "hard-budget constraints" could induce more damage to social stability in macro policy (Chen 2006). A state policy of restructuring would be very critical to an industrial transition. For the firm's survival and long-term development, control of the board must have a well-defined multi-dimensional goal, not a simple-minded short-term maximization of the shareholder's value.

Fourth, the wide spread illusion of fair competition with symmetric information creates a utopia of fair game in market regulation. That is far from reality. Any innovation in the division of labor increases information asymmetry and power asymmetry in human society. This is the root of "creative destruction" including entry barrier, patent protection, state boundaries, culture discrimination, and war. The vital challenge is maintaining a difficult balancing between innovation and sustainability. The misleading fantasy in the Coase theorem is his symmetric assumption between polluters and victims and implicit symmetry between consumption and investment (Coase 1960; Cheung 1998). Voluntary exchange may not be reached in dealing with conflicting interests such as pollution, if bargaining positions are excess asymmetric or even hostile (Chen 2007b). This is why legal protection of disadvantaged groups is necessary for sustainable market. New institutional economics ignored the basic lesson from political economy that power is associated with large asymmetry in wealth distribution. Therefore, the equilibrium strategy based on liberalization and privatization without home-grown competition mainly paved the way for foreign financial power in EEFSU. The same was true for the Asian financial crisis in 1997.

In sum, changing property rights and organizational structure is an integrated part of evolutionary dynamics driven by a changing macro environment and industrial technologies. Simple-minded profit maximization or costs reduction is not a working strategy in an open economy with the rise and fall of technologies.

14.6 Conclusion

The issue of corporate governance is mainly based on the American experience of separation of ownership and control in large corporations at a mature stage, which is less relevant for emerging companies at a developing stage. Some measures like accounting standard and independent board directors do have merits for developing a global financial market. But the relation between corporate governance and economic performance is a complex and evolving issue without simple solutions.

The Coase approach of transaction costs and the theory of property rights raise interesting issues on coordination mechanism inside a firm. But the equilibrium perspective based on costs reduction (in the form of transaction costs or agency costs) is not capable of understanding the creative nature of the firm and evolutionary dynamics of organizational changes. The Japan experience in corporate culture and China lesson under mixed property rights shed new light on the selective mechanism for organization development and life cycle in changing ownership structure. An evolutionary perspective may provide a new framework in understanding diversified patterns in corporate governance and the rise and fall of firms and nations (Dopfer 2005; Chen 2005, 2007b).

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Part V

Market instability, natural experiments, and government policy

15 Market instability and economic complexity

Theoretical lessons from transition experiments[1]

15.1 Introduction: the forgotten lessons from the Great Depression

There were two conflicting views on the nature of market economy and business cycles. The "equilibrium school" in classical economics believes that market economy is essentially stable because of mean reverting mechanism of demand and supply forces, and as such economic fluctuations are primarily driven by external shocks (Frisch 1933). In contrast, the "disequilibrium school" asserts that the market economy is like a biological organism (Schumpeter 1939), which has both dynamical instability and a coherent structure. Innovation and technological progress are essentially unstable, and they are characterized by creative destruction, technology replacement, and biological rhythm. For policy analysis, equilibrium school focuses on short-term deviations from equilibrium state, while disequilibrium school mainly focuses on medium and long-term dynamic patterns and structural changes.

Natural experiments play a key role in testing competing economic theories. The Great Depression shook a widespread belief in inherent market stability. The rise of Keynesian macroeconomics made a revolutionary contribution relating to the definition of involuntary unemployment, destabilizing financial markets, and role of government in managing business cycles (Keynes 1936). However, the Keynesian revolution only partially succeeded in macroeconomic theory. The Keynesian school did not develop a general theory of dynamic disequilibrium that was capable of explaining financial crisis and economic complexities (Galbraith 1994). Methodologically speaking, equilibrium processes without history (nonlinearity) and diversity (multiple equilibriums) are easier to model mathematically. Equilibrium theories are developed as a form of armchair economics and are without solid foundations in empirical observations. Microeconomic theory based on complete markets, perfect competition, and optimization behavior leave no room for technology innovation and market instability.

There are a wide range of economic theories. The Arrow–Debreu general equilibrium model generates a utopian market with unique stable equilibrium that has no disruptive technology and learning space (Arrow and Debreu 1954). The efficient market hypothesis in finance theory claims stock prices are always right, which implies that there is little chance of financial crisis occurring (Fama 1970). The property rights school further excludes path-dependence and multi-equilibrium from institutional evolution. According to the Coase theorem, optimal institutions can be established by voluntary exchange of property rights, which is independent of initial conditions (Coase 1990). The new classical school, led by Lucas, launched a counter Keynesian revolution in macroeconomics (Lucas 1972, 1981). According to the theory of rational expectations and microfoundations, involuntary unemployment is no longer a significant problem in economic policy, since unemployment is redefined as a rational choice between work and leisure at individual or household level. The main hypothesis within the so-called "Washington consensus" might be considered part of this counter revolution, which not only rejects any contribution from socialist experiments in industrialization and community-building, but also negates Keynesian policy in dealing business cycles and financial crises (Williamson 1990).

If we accept that economics should be considered to be an empirical science, not simply a subset of philosophy, is it possible to test competing economic theories through policy experiments? Our answer is "yes." Recent events from the transition economies provide us with a good opportunity for testing economic theories.

The so-called Washington consensus (or shock therapy approach) was derived from standard equilibrium theory (Williamson 1990; Sachs 1992). Based on their equilibrium-optimization belief, the system of property rights and hard-budget constraints could ensure firm level efficiency in a competitive marketplace; the flexible price system created by liberalization policy should lead to both stability and efficiency in competitive market; economic growth would be driven by foreign direct investment and technology diffusion from developed economy after liberalizing trade and exchange rate. Under these assumptions, economic transition and development is simply a convergent process without the need of policy experimentation and institutional innovation (Sachs and Woo 2000). If we consider the rich physical and human resources in Eastern Europe and the former Soviet Union (EEFSU thereafter), it would be natural to predict that EEFSU would grow at a much faster rate, while China would struggle with its poor resources, cultural burdens, and political institutions. The surprise of the large output decline in EEFSU and rapid development in China raise serious questions about the validity of textbook equilibrium economics, especially in relation to its theory on market mechanisms and economic development (World Bank 2002).

Transition economies between the 1970s and 1990s have several features that are different from the industrial economies during the Great Depression. First, there were no major military conflicts or international crises before or during the transition process. Second, severe output declines during the transition process were not driven by stock market crashes or banking crises. These two features made the background of transition experiment much simpler than that of Great Depression in theoretical terms. Third, the difference in economic performance during transition was mainly caused by policy differences between EEFSU and China; the former is characterized by "shock therapy" or liberalization policies driven by the so-called Washington consensus (Sachs 1992; Williamson 1990) while the latter is characterized by a gradual approach with decentralized experiments and a dual-track price system (Lin 1992; Chen 1993c). In contrast, no theoretical dividing line emerged in policy debates during the Great Depression. Therefore, transition experiment can serve as a better touchstone in testing competing economic theories because of its relative simplicity in historical comparison.

The shock therapy approach originated in Latin America, and was then applied to EEFSU. The experimental approach was rooted in the East Asian mode of industrial policy, managed trade, and dual-track price system for export-led growth. The different performance in economic growth can be seen in Table 15.1.

From Table 15.1, we can see two remarkable facts. First, there was no evidence for the widespread belief that socialist economies collapsed in the 1970s and 1980s, even though there was a visible slow down for both developed countries and EEFSU. The wave of economic reform and transition in socialist countries was mainly driven by political factors rather than economic crises in the 1980s. Second, there was a sharp contrast between the "Transition Depression" in EEFSU and continued growth in China and Vietnam amongst the transition economies. We will consider the economic performances associated with transition economies as a natural experiment, in addition to the economic outcomes following the Great Depression, both of which are valuable in studying the unstable and complex nature of macroeconomic dynamics.

Table 15.1 Average GDP growth rate in decades (%)

Decade	*1970s*	*1980s*	*1990s*
East Asia	4.5	4.4	2.8
East Europe	4.8	2.4	–4.4 (46% in absolute decline)
West Europe	2.7	1.9	1.6
North American	3.3	3.0	2.8
South American	5.2	1.2	2.9
World	3.6	2.7	2.1
Japan	4.2	3.6	1.2
German	2.6	1.7	1.6
China	4.7	8.8	9.4
Vietnam	–0.1	5.0	6.9
Poland	6.1	0.9	3.2
Hungary	4.7	1.5	0.3
USSR	4.6	2.6	
Russia			–4.8
Ukraine			–8.9

Source: United Nations Statistics.

15.2 The stylized facts in the Great Depression and the Transition Depression

The main facts in the Great Depression and the Transition Depression are shown in Table 15.2 and Table 15.3. We can see the degree of the Transition Depression is comparable or even more severe than the Great Depression. Polish economists even coined the term "The Greater Depression" for the recession that occurred in EEFSU (Kolodko 2000).

We were surprised by the depth of the Transition Depression. US industrial output was down 47 percent, its real GDP declined by about 25 percent, and the recovery to pre-Depression level took approximately 14 years; China's economic depression (caused by famine in the late 1950s) lasted five years with 32 percent decline in GDP. However, the Transition Depression in Romania, Bulgaria, and three other countries in the former Soviet Union lasted more than 16 years; their GDP levels now (2005) are still below those levels achieved before the transition. The decline in real GDP ranged from 43 percent in Russia, 60 percent in Ukraine, and even 73 percent in Georgia. The magnitudes of the Transition Depression were more severe than those in the Great Depression in US and most other European countries at that time.

There are several theories proposed to explain the Great Depression: The financial instability caused by World War I in Europe, the stock market crash in the US, and the deflation caused by the British return to the Golden Standard; and the human error in the determination of monetary policy (Romer 2004). Many economists share the consensus that the endogenous instability in the financial market played a major role in the Great Depression. In contrast, there was only a minor slowdown, no financial crisis in socialist economies in EEFSU before the transition in early 1990s. The rapid transition in Eastern Europe was marked by the fall of the Berlin Wall in 1989 and the break-up of the Soviet

Table 15.2 Industrial decline in the Great Depression (1929–1942) (measured by peak-to-trough decline in industrial production)

Country	*Decline (%)*	*Peak–Trough date*	*Recovery date*	*Length*
US	46.8	1929.3–1933.2	1942	14 yrs
UK	16.2	1930.1–1932.4		
France	31.3	1930.2–1932.3		
Germany	41.8	1928.1–1932.3		
Canada	42.4	1929.2–1933.2		
Italy	33.0	1929.3–1933.1		
Poland	46.6	1929.1–1933.2		
Czechoslovakia	40.4	1929.4–1933.2		
Japan	8.5	1930.1–1932.3		

Source: Romer (2004).

Note
Here, the year and month in peak–trough date is separated by period. For example, 1929.3 means March 1929.

Table 15.3 The Transition Depression in EEFSU (measured by peak-to-trough decline in real GDP)

	Peak	*Trough*	*Recovery*	*Length (years)*	*Decline (%)*
Germany	1992	1993	1994	1	–1.1
[East Germany declined 30% in 1991, its GDP in 1992 was only 7% of unified Germany.]					
Czech	1989	1993	1999	10	–13
Slovakia	1989	1992	1998	9	–22
Poland	1989	1991	1996	7	–18
Hungary	1989	1993	2000	11	–18
Romania	1987	1992	2005	18	–30
Bulgaria	1988	1997	>2006	>18	–34
Albania	1989	1992	2000	11	–40
Estonia	1990	1994	2002	12	–45
Latvia	1990	1995	2006	16	–50
Lithuania	1990	1994	2005	15	–44
Russia	1990	1998	>2006	>16	–43
Ukraine	1990	1999	>2006	>16	–61
Belarus	1990	1995	2003	13	–45
Georgia	1990	1994	>2006	>16	–73
Uzbekistan	1990	1995	2001	11	–20
Azerbaijan	1990	1995	2005	15	–58
Kazakhstan	1990	1998	2004	14	–38
Tajikistan	1990	1996	>2006	>16	–67
Turkmenistan	1990	1997	2006	16	–41
Mongolia	1989	1993	2002	13	–23

Source: United Nations Statistics. Recent data from CIA *World Factbook* (2006).

Union in 1991. The wholesale liberalization in exchange rate, trade, price, and rapid privatization carried out with ideological fever in EEFSU, while China and Vietnam were cautious in preserving social stability and export-led growth.

We should examine the main cause of the Transition Recession in EEFSU. Let us start with the simplest case in transition process, East Germany after German unification (Münter and Sturm 2005).

15.3 Monetary power and trade imbalance in non-equilibrium world

Some economists blamed the Transition Recession on "bad politics" rather than "bad economics" (Roland 2000). For example, Sachs pointed out that insufficient level of Western aid was the main cause of Russia's failure to stabilize its currency (Sachs 2005). Disruption of production chains and credit tightness were significant factors in output decline (Blanchard and Kremer 1997; Calvo and Coricelli 1992). However, the case of German unification offers a clear clue to the primary reason for output decline in EEFSU. This culprit is exchange rate liberalization.

The best example of shock therapy (without Sachs' concern over the problem of insufficient aid) occurred not in Poland, but East Germany (Kolodko 2000; Burda 2008). After German reunification in 1990, East Germany completely imported the system of property rights and legal infrastructure from their West German neighbors. West Germany provided the most generous financial transfer in history, which is about approximating €80–90 billion per annum or 20 percent of East German GDP, which is much larger than the amount allocated as part of the Marshall Plan following World War II or indeed any amount of foreign aid to a single developing country. There was essentially zero inflation and macro instability in East Germany. Using Barro's convergence measurement, the wage rate, consumption, productivity, and other economic indicators in East Germany, converged to those of West Germany more rapidly than that predicted by neoclassical growth theory (Burda 20086; Barro 1991). However, there is slow economic growth and the unemployment rate in Eastern Germany is still rising 15 years after unification. Why have convergence theory and the property rights hypotheses failed to produce an East German miracle under the most favorable transition conditions in industrial history?

In 2004, we undertook a field observation at the famous Zeiss Optical Company in Jena of Eastern Germany. We were surprised by the large negative shock of switching exchange rate regime. Although Zeiss products were the most advanced and competitively produced in the global market, the company suddenly lost more than 90 percent of the market share in Eastern Europe after German reunification, because existing customers could not afford to pay in former Soviet bloc currencies. Accumulation of hard currencies used in the West is a relatively slow process in developing countries and in transition economies. It is an outcome of learning process, including increasing competitiveness, building market network, and the accumulation of foreign reserve, rather than reaching the equilibrium state overnight in exchange rate market. We may speculate that the breakdown of CMEA (Council for Mutual Economic Assistance) and industry overkill in EEFSU was mainly caused by radical liberalization in foreign trade and the exchange rate.

The slow convergent process in international trade can be revealed from China's dual-track foreign exchange system, which lasted about 15 years from April 1980 to January 1995. China's international trade was in deficit of US$1.8 billion in 1980. However, this grew to a trade surplus of $5.4 billion in 1994, and $24.1 billion in 2000. Accordingly, its accumulation of foreign reserves increased from US$0.8 billion in 1979, to $51.6 billion in 1994, to $165.6 billion in 2000. China's dual-track foreign exchange system successfully merged in 1994, at a time when its foreign trade had moved from deficit into surplus after 15 years of reform and export-led growth (Figure 15.1). China's annual export growth rate was 26 percent in the 15 years from 1979 to 1994, which was more than twice the growth rate of annual GDP growth rate in the same period (9.5 percent). In contrast, the trade liberalization in EEFSU induced a flood of imports rather than an increase in export growth. As observed by a Polish economist, "the more rapid the liberalisation of trade, the bigger the initial shock and the deeper the ensuing recession" (Kolodko 2000).

After the Asian financial crisis in 1997, there were an increasing number of economists who realized the danger of excess international capital mobility since

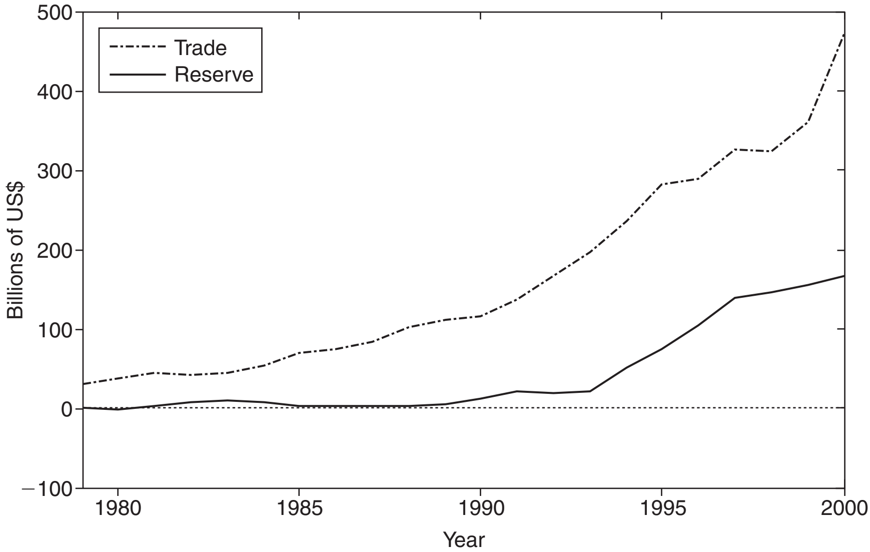

Figure 15.1 China's trade surplus and foreign reserves (1979–2000) (source: China Statistics 2001).

it encourages international speculation in financial markets. Mainstream economists argue for a flexible exchange rate in order to create an anchor for macroeconomic stability. However, these economists ignore the reality of unequal competition and the monetary power associated with international trade and finance. In neo-classical monetary theory, money and exchange rates are simply treated as the media of exchange in a utopian general equilibrium world. In the far-from-equilibrium real world, hard currency also engenders market power associated with political economy (Goodhart 1998).

There is no role for the "selective filter effect" created by currency control in equilibrium theory of monetary economics. Evolutionary economics has more to learn from evolutionary biology, where the emergence of biological structures, such as cell membranes, plays an important role in the origin of life. Selective open membrane in organism is equivalent to a *Maxwell demon* in living system, which allows positive matter flow, energy flow, and information flow, but rejects harmful flows for maintaining dissipative structures in open system (Prigogine and Stengers 1984). Without the protection of biological borders, no living being can maintain a living organism under far from equilibrium conditions. This is an essential difference between mechanical machine and biological organism. In political economy terms, custom, credit, standard, visa, and other security systems closely guard developed economies, which are *not* "*free*," but *selectively open* to the world market. The promoters of free trade and free capital market simply ignore the needs of developing countries for creating learning space and defense wall against negative shocks from international market. The argument for liberalization policy is attracting foreign direct investment (FDI). However, trade liberalization plus macro instability led additional capital flight and asset stripping in EEFSU. China's success in attracting FDI mainly resulted from growing market and sound macroeconomic policy, not from property rights and liberalization policy.

15.4 Complex dynamics, path dependence, and learning space

According to neo-classical microeconomics, a complete market economy (without innovation space and product cycles) has a unique equilibrium in general equilibrium microeconomics, which is inherently stable because of the atomic mechanism (i.e., no supply chains or network in division of labor) of supply and demand (Arrow and Debreu 1954). An optimal system of property rights can be achieved by exchange without historical constraints (Coase 1990). Therefore, the convergence school hypothesis predicted a relatively quick stabilization process after price liberalization and the establishment of property rights. Surprisingly, immediate results of liberalization policies in EEFSU led to inflation spirals, excessive devaluation of currencies, and widespread output decline (see Table 15.4 and Table 15.5).

Equilibrium theory such as the purchasing power parity has little power to understand the large currency depreciation during transition. For example, from 1990 to 1998, Russia's real GDP measured by 1990 US dollars declined 43 percent, but its currency depreciated 5534 times from 1991 to 2000! This is a clear case of nonequilibrium process.

One visible feature in China is its remarkable stability in the inflation rate and exchange rates, which can be seen in Table 15.4 and Table 15.5. However, situations vary greatly in EEFSU. Can we understand these differences by new thinking in evolutionary economics and complex dynamics? We propose two possible explanations: path-dependence and learning space.

Table 15.4 Peak inflation rate during the transition (measured by the implicit price deflator in national currency)

Country	*Peak inflation (%) (year)*	*Length of high inflation (>40%)*
Germany	9 (1990)	0
China	13 (1988), 20 (1994)	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.

Table 15.5 Devaluation of currencies (exchange rate set at 1 in 1980 or 1991)

Year	*1980*	*1985*	*1990*	*1991*	*1993*	*1995*	*2000*
Germany	1	1.6	0.9	0.9	0.9	0.8	1.2
China	1	2.0	3.2	3.6	3.9	5.6	5.5
Czech			0.8	1	1.0	1.0	1.4
Slovakia			0.6	1	1.0	1.0	1.6
Hungary	0.44	0.7	0.9	1	1.2	1.7	3.8
Poland		0.01	0.9	1	1.7	2.3	4.1
Bulgaria				1	1.6	3.8	0.1
Romania	0.22	0.24	0.29	1	10.0	26.6	284
Belarus			0.51	1	191	47,937	108
Russia				1	195	897	5534
Ukraine			0.5	1	634	20,602	76,087

Source: Penn World Table 2002.

Notes
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.

15.4.1 Inflation constraints and path-dependence

One interesting finding is that those countries with low inflation rates, including China, Germany, the Czech Republic, Slovakia, and Hungary, suffered painful periods of hyperinflation in the first half of the twentieth century. The collective memory of previous hyperinflation during the civil war in China and between the two world wars in Central Europe created a behavioral constraint in monetary policy in these countries. In contrast, new hyperinflation occurring in the former Soviet Union, which had a long history of fixed prices under a command economy, was without near historical precedent. *History* or path-dependence *matters in economic behavior* (David 1985; Arthur 1994)! It is often assumed in macro dynamics that price movements follow Markovian processes, which have no historical memory. Now we understand it is rarely true under nonlinear dynamics (Chen 2005). History tells us a different reality.

15.4.2 Complex patterns under a dual-track price system: production cycle and roundabout production

The most visible innovation in China's reform was the introduction of the dual-track price system in the mid-1980s and continued after the failed attempt of shock therapy in terms of price reforms in 1988. There were twofold objectives in introducing the dual-track price system. The first was to maintain social stability with fixed prices and food rationing under the central planning system. The second was to provide production incentives by ensuring payment at market prices when firm production exceeded the levels of government quotas. The resulting price dynamics varied greatly in product markets, which provided rich evidence of industrial structure and complex dynamics.

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 in place (on and off) for more than ten years, and never fully liberalized. The price of industrial products were rapidly liberalized and deflation for consumer goods and luxury products occurred in places, but market liberalization for basic consumption goods was much slower. The prices for energy, utility, education, and health care are still under tight control despite a persistent trend of price inflation, because their supply persistently falls behind social demand when income grows rapidly (see Figure 15.2). Price dynamics are complex with complicated interactions among changing micro behavior, varying product cycles, interdependent industrial structures, and cyclic macro environment.

One possible explanation for the varied pattern in price dynamics is the varied length of production cycles. The production cycle for vegetables and meat is several months; however, the investment cycle for power stations require several years. Additional complexity can be added as a result of roundabout production in division of labor (Hayek 1935). This is greatly different from the simple supply–demand mechanism among farmers without network constraints. Grain and cotton have a similar length of production cycle (in terms of length) as those of vegetable and meat. However, cotton and grain can also be used as input for later industrial production, and as such price fluctuations in grain and cotton markets are much greater and more persistent than those in vegetable and meat markets. China's price reform in grain and cotton markets was much slower than other agriculture markets. The existence of inventory cycles and future markets introduce additional complexity in grain and cotton markets. The Chinese government made great effort in managing price stability and stimulating growth for ensuring social support during reform process.

The difference in industrial structure between China and EEFSU may have partially contributed to their difference in agriculture reform. The family contract system worked well for China's small-scale farm production, but failed to work for large-scale mechanized farm in the former Soviet Union.

In summary, the simplistic picture of a Robinson Crusoe economy in neoclassical economics cannot explain business cycles and divergent evolution in division of labor (Chen 2002). Modern farm industries are also highly correlated because of industrial supply of seeds, fertilizers, and other farm production inputs. The observed price cycles in grain, cotton, and many industrial prices have significant degree of volatility. A market system will be remarkably stable under external shocks, if supply and demand curves have only unique equilibrium and negligible time-lag. However, market dynamics will be unstable or even chaotic when exists multiple equilibrium or substantial time-lag (Chen 1987a, 2005). Dynamic complexity and transition uncertainty created the need for decentralized experiments and dual-track reform, since these reform strategies created a learning space for market forces and regulating agencies in

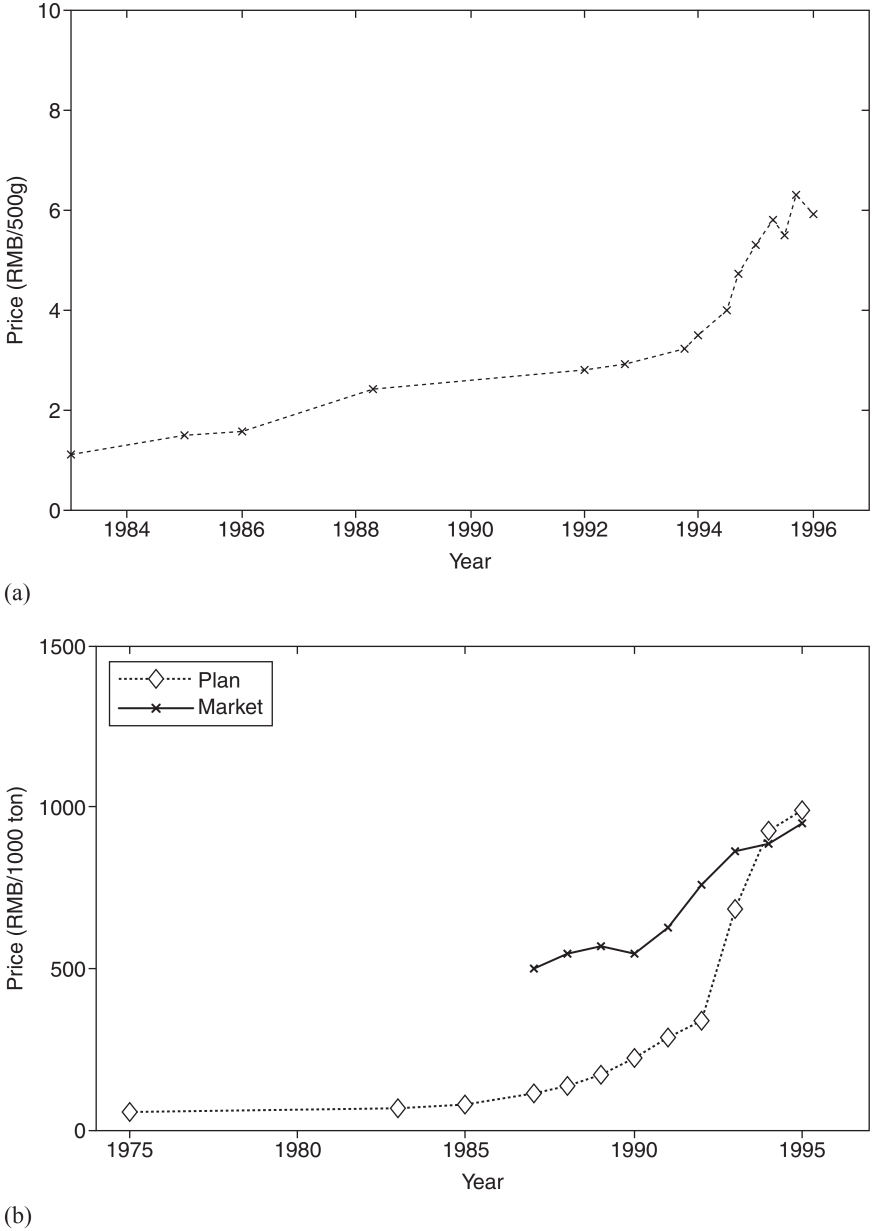

Figure 15.2 Price history in Shanghai local market. (a) Fresh pork price (1983–1996). (b) Heavy oil dual-track price (1975–1995).

adapting changing market and changing behavior. The blind-confidence in general equilibrium theory led to the naive strategy of shock therapy in EEFSU. When the whole system collapsed people lost their basic sense about which direction to move.

15.5 Conflicting analysis in equilibrium thinking and economic policy

The Washington consensus seems to provide an integrated approach for transition and development economies. However, the Washington consensus proposes too many conflicting goals without an operational strategy or reform sequence. For example, while large-scale privatization and rapid institutional change created fiscal crisis and weak government, it has shaken social confidence in market economy. The Lucas idea of microfoundations of macroeconomics ignores the complex nature of economic organism and the whole entity being greater than the sum of the parts. We will discuss lessons from transition economies, in order to seek a better alternative than the equilibrium perspective and methodological individualism.

15.5.1 Hard-budget constraints and credit crunch

Kornai singled out the soft-budget constraint (in the form of government subsidy to money-losing firms) as the main cause of inefficiency of firms under socialist economies (Kornai 1986). This logic is true only for a closed economy without technology progress or credit markets. This is the fundamental weakness of the complete market hypothesis. In industrial societies, soft-budget constraints widely exist in various forms, including bank credit, venture capital, and bankruptcy law. American bankruptcy law of Chapter 11 offers a reorganization opportunity for firms in financial difficulty and a chance of eventual survival. Chrysler and the Long-Term Capital are well-known example of "too big to fail" or soft-budget constraints in capitalism. In practice, the credit crunch by imposing "hard-budget constraints" is an additional cause of the output decline in EEFSU (Calvo and Coricelli 1992).

When open-door policies introduce international competition to domestic firms, the critical choice is how to upgrade technology for a domestic firm's survival. A favorable macroeconomic environment, including access to bank credit and capital market, is very important in a firm's survival in a globally competitive market. Sachs and Woo (2000) argued that China's market oriented reform should be much easier than Russia's since China's rural population has no social security. If this is true, developing countries such as Bangladesh may grow faster than China! The real reason behind China's rapid technology progress is its state insurance during learning process. Farmers' down-side risk is protected by collective ownership of land, thus preserving positions for those in business adventures. China achieved rapid economic growth and technological advancement exactly under the policy of so-called soft-budget constraints. Many state owned enterprises (SOEs) and township and village enterprises (TVEs) made rapid progress in international competitiveness, which can be seen from double-digit growth of manufacturing exports in China. From the view of property rights school of thought, both SOEs and TVEs have no clear delineation of property rights. In financial practice, shares of local governments could enhance firm's credit for 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 win* scenario through informal privatization: if SOEs or TVEs succeed in new product markets, they are privatized; when failure occurs, the state-owned banks absorb the financial loss. In this way, China's state sector took the main cost in technology acquisition and business venture activities in the non-state sector. The NPL contains several components of learning costs, efficiency loss, and social burden. Comparing to credit tightness under the policy of hard-budget constraints, the cost of transition depression in EEFSU is much larger than the NPL in China. Whether China's growth under soft-budget constraints can be continued, the answer does not depend on the quantitative cost of soft-budget constraints, but the productivity gain over and above the social cost. The same is true for America's growing trade and budget deficit. China's growth oriented development strategy is a new type of Keynesian policy, while Kornai's policy of hard-budget constraints simply a new form of the new classical counter Keynesian revolution. The history in transition economies provides strong evidence that the macro environment for micro (firm) behavior is more significant than the so-called microfoundations of macro stability.

Theoretically speaking, the theory of soft-budget constraints is a somewhat naive exercise in microeconomics, but a dubious theory in macroeconomics. If the survival of majority rather than minority of socialist firms only depend 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 has postulated the wrong diagnosis of the trade-off between planned economy and market economy. As Schumpeter pointed out, capitalism is driven by innovation, which is intrinsically unstable. Business cycles and financial crises are the price paid for creative destruction in open economies. In contrast, socialism is more stable in closed society. The main weakness of planned economies is not the lack of incentives, but the stagnation of technology. Therefore, the right direction for reforming socialist economies is not creating a pure private economy with hard-budget constraints, but a mixed economy open to world market and new technology.

15.5.2 The MM theorem and the property rights school

The property rights school claims that private ownership is a necessary condition for market efficiency, which is the main belief behind privatization policy.

However, the MM theorem in financial economics implies that the debt structure, or alternatively, the ownership structure, does not matter for firm's value in competitive market (Modigliani and Miller 1958). From a governance point of view, there is no essential difference between state firms without clear delineated ownership and private firms with diversified ownership. Technology, management, corporate strategy, and economies of scale all matter in market competition. There is no question that excessive state ownership crowds out private innovation; that is why privatization of small and medium firms is successful in many countries. However, there is no solid evidence that privatizing large firms would always improve competitiveness and efficiency (Von Weizsacker *et al.* 2005). China's secret of low labor costs in export industries is rooted in its mixed social security system. In particular, the social security of large rural population is based on the collective ownership of land. If China would privatize collectively owned land, its infrastructure development and export growth would slow down dramatically.

15.5.3 Privatization vs. competition policy

Under socialist systems, large state firms often have monopolistic positions in industry. Large oil and utility firms generate important revenues for government. Competition policy is a means of breaking down state monopolies, just like breaking up AT&T in US was the effective way to improve efficiency in the telecommunicating market. This type of success story is also seen from the breaking up of China Airways into several competing companies. However, privatizing large firms without mitigating monopoly power made the situation worse in Russia. The government not only lost significant revenues, but also public support for privatization. Local government was forced to change from a "helping hand" approach into a "grabbing hand" (Frye and Shleifer 1997). The collapse of public finances led to the rise of mafia economy. The simultaneous liberalization, stabilization (financial squeezing under the name of hard-budget constraints), and privatization created vicious circles and chain reactions of output decline, persistent unemployment, hyper inflation, currency devaluation, fiscal crisis, capital flight, and asset stripping. The Transition Depression was a man-made disaster, while the Great Depression was an outcome of market bubble and financial crisis.

15.6 Conclusion

Both the Great Depression and the Transition Recession are two natural experiments, which have stimulated new economic thinking for generations of economists. Keynes learned an important lesson on macro instability and emphasized the role of active government in maintaining social stability. Certainly, the experiences of welfare state in industrial countries also revealed the limits of large government in job creation and technology advancement. The transition experiments in EEFSU and China provide new lessons on co-evolution of changing economies and innovative government, which is relevant not only for developing economies, but also for developed economies. We need a more general framework, which could integrate historical lessons from market instability and economic complexity in the evolution of the division of labour. We will briefly discuss the theoretical lessons from transition economies.

Stiglitz (2004) rightly concluded that "the [oversimplified] Washington consensus did not provide the answer for development strategy. There was a failure in understanding economic structures within developing countries." Roland (2000) pointed out the importance of "the evolutionary-institutionalist perspective" in understanding transition economies. Sachs (2005) finally realized that "economies [like the human body] are complex systems; … economist, like medical clinicians, need to learn the art of differential diagnosis." These observations are worthy of further theoretical analysis.

First, general equilibrium theory in neo-classical microeconomics is a static model in nature. Many economists admire its mathematical simplicity and theoretical elegance, but few realize its limitation in policy implications. In the utopian model of complete market under perfect competition, consumers have no subsistence threshold and social interactions, all products have infinite life without technology replacement and product cycles, price is the only variable in adjusting resource allocation (without the need of business strategies and product innovation), and the implicit speed of adjustment is infinite without any delay or possibility of overshooting. Any violation of one of these "perfect" conditions results in the price equilibrium being neither unique nor stable. That is why shock therapy in price liberalization led to inflation spiral in EEFSU but gradual approach with dual-track prices made smooth transition in China's price reform. Future microeconomics should construct more realistic market model with financial access, complex networks, and nonlinear dynamics.

Second, methodological individualism or the Robinson Crusoe economy in neo-classical macroeconomics abstracts out the critical link of financial intermediates between micro firms and macro economy. There is little understanding of financial crisis through the efficient market hypothesis in finance theory. There is weak evidence of "microfoundations" of macroeconomies, but strong evidence of "macro environment" for micro behavior because of the Principle of Large Numbers (Chen 2002). Macroeconomy can be better described by three layer model: macro–meso (financial intermediate and industrial structure)–micro. It is the original idea of financial Keynesian economics that financial instability is an important source of macroeconomic boom and bust (Minsky 1985).

Third, social evolution and institutional development in an open economy is a divergent process like biological evolution, while the prediction of transaction cost or property rights school is a convergent story in closed systems. Historical constraints and institutional innovations play no role in Washington consensus. Under uneven distribution and nonequilibrium development, "disciplined hand" in positive development requires more constraints than protecting property rights (i.e., the "invisible hand") during the reform process. Protecting competition and innovation is indispensable in market economies. Monopoly, corruption, organized crime, and income polarization may destroy the social foundation of a market economy. The modern history of science and capitalism reveals the importance of checks and balance in mixed economies with private, public, and non-profit non-government sectors (Samuelson 1961). Institutional economics should better understand the historical lessons of mixed economies and study new international order in the twenty-first century.

Fourth, equilibrium perspective in world development is simply a linear trajectory towards the "end of history" (Fukuyama 1993). The question is how to understand the rise and fall of nations in transition economies. From the view of complexity science, there is a trade-off between complexity and stability in evolutionary dynamics (Chen 1987a, 2005). Under stable environment with moderate fluctuations, development of division of labor will increase economic diversity while severe fluctuations will reverse the trend back into barter or self-sufficient economy. The ecological dynamics of learning competition may help understand the nature of evolutionary dynamics (Chen 2005).

In sum, equilibrium approach ignores two main sources of market instability and economic complexity: nonlinear interactions with multiple equilibriums and collective behavior with fads and dreams. Market forces without government management and social coordination cannot achieve healthy development under rapid technology advancement and unequal global competition. Evolutionary perspective and complex economics offers a better alternative in understanding economic development and institutional changes.

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16 From an efficient to a viable international financial market[1]

16.1 Introduction

This ongoing Grand Crisis originated in the United States, then transmogrified into an international crisis. It represents a natural experiment. The positive side of this crisis is its fundamental lesson. It is not a theoretical debate confined to ivory towers, but a historical event that has destroyed social confidence in the mainstream equilibrium theory of the so-called efficient market. This has accelerated the rise of the nonlinear evolutionary theory of the viable market. Three observations reveal where the equilibrium theory of asset pricing and business cycles went wrong: (1) the meso foundation of macro fluctuations; (2) the endogenous nature of persistent cycles in financial macro indexes; and (3) the trend of collapse and higher moment risk in the derivative market. The new perspective of nonlinear population dynamics in continuous time provides a better alternative to existing rational-actor/linear models of finance, not only for understanding the cause of the present situation, but to inform efforts related to redesign and reform. The systematic failure in the mortgage security market, unprecedented concentration in the international financial market, and unfettered speculation in the commodity and currency markets have all contributed to the current disaster. A new international financial order can be achieved if a robust and workable international antitrust law can be enacted and a Tobin tax on foreign exchange transactions can be established through global efforts. An overhaul of financial theory is needed to develop a viable market for sustainable economies.

16.2 Empirical observations and policy implications: econometric illusion in the efficient market and an alternative strategy for a viable market

Our empirical analysis of business cycles draws on tools developed by the new science of complexity and nonlinear dynamics, which were applied to US economic time series (Chen 1988a, 1996a, 1996b, 2002, 1999). The policy recommendations were reached based on alternative scenarios tested under the rubric of nonlinear evolutionary dynamics in finance and economics (Chen 2005, 2007a, 2008). The debate begins by examining the nature of business cycles, before proceeding to study the misleading role of linear models in asset pricing.

16.2.1 Endogenous nature of US persistent business cycles and a new perspective on risk management

What was the nature of the US financial crisis? US Federal Reserve Chairman, Ben Bernanke (2005), has attributed it to over-consumption in the United States and over-saving in China, while Treasury Secretary, Tim Geithner (2009), has blamed China's exchange rate policy. The hidden assumption behind Bernanke or Geithner theory is that this financial crisis was mainly caused by external rather than endogenous causes. Therefore, the first fundamental issue is the nature of business cycles. Are they generated by external shocks (Frisch 1933; Lucas 1972) or by internal instability (Schumpeter 1939; Chen 1988a, 1996a, 1996b)? This issue is essential, since all textbook investment strategies related to diversification and hedging are based on a simple assumption that an efficient market is characterized by a random walk or Brownian motion, without countenancing the possibility of nonlinear deterministic patterns such as persistent cycles and chaos (Friedman 1953; Fama 1970, 1991; Black and Scholes 1973). The application of a new technique of time–frequency analysis based on WGQ (Wigner–Gabor–Qian) transformation in time–frequency space has led to the development of a powerful tool for nonstationary time series analysis, which can replace those conventional models (Chen 1996a, 2005, 2008). Solid evidence of endogenous persistent cycles is shown in Figure 16.1, while the equilibrium illusion of white noise is simply created by the first difference (FD) filter (Figure 16.2), which is a high-frequency noise amplifier by nature (Chen 2008).

As shown in Figure 16.1, deterministic cycles can explain 65 percent of variance from HP-detrended cycles filtered by WGQ transformation in time–frequency space. The cross-correlation with original cycles is 0.94. We found these persistent cycles can be explained by color chaos. Color means that its intrinsic period is about four to five years. Color chaos is deterministic chaos in continuous time. Its correlation dimension is about 2.5 (Chen 2005). Color chaos can be considered as the nonlinear model of Schumpeter's biological clock, a better alternative model of random walk or white noise in equilibrium theory of business cycles.

From Figure 16.2, we may easily find out that FD filter is a whitening device, which suppresses low-frequency signals in business-cycle range but amplifies high-frequency noise. This is the central device in creating an equilibrium illusion of an "efficient market" which is characterized by white noise or random walk in Wall Street.

What can be learnt from these observations? First, white noise plays only a non-dominant role in the financial market. For example, the white noise component represents only about 35 percent of the variance of the HP-filtered cycles. Second, the equilibrium theory of efficient markets provides a distorted image of reality. We find that the intrinsic frequency of stock market indexes is remark-

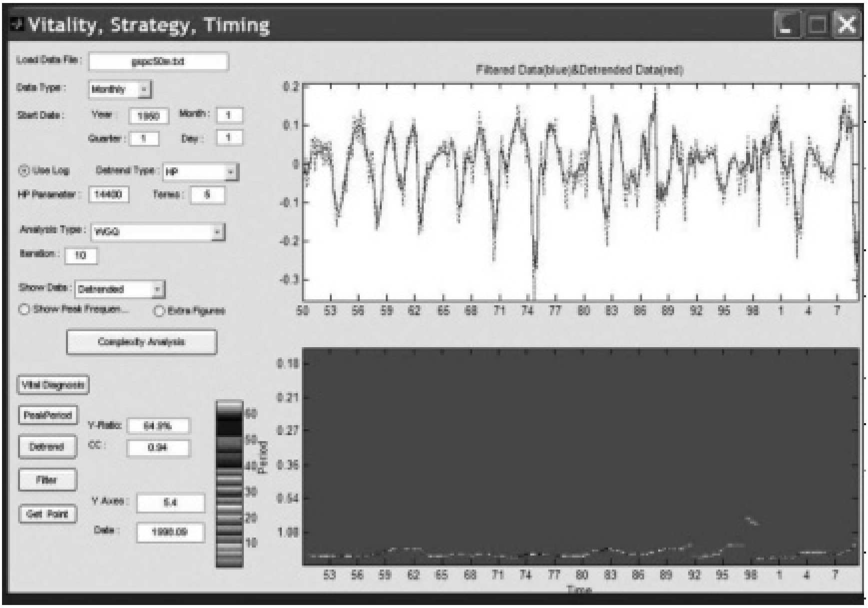

Figure 16.1 Nonstationary time series analysis based on WGQ (Wignor-Gabor-Qian) transformation (source: data used is GSPC (Standard & Poor 500 index) monthly (January 1950 to April 2009) (http://yahoo.finance).

Notes
The upper diagram shows the original (the dotted line) and filtered (the solid line) HP cyclic time series. Y-ratio (the variance of the filtered time series to the variance of the original one) is 64.9 percent. CC (their cross-correlation) is 0.94. The lower diagram shows the time trajectory of the characteristic period of the HP cyclic series. The vertical axis is the period in years, the horizontal axis is time from 1950 to 2009. The period trajectory is more or less moving around the NBER business cycle frequency.

ably stable about the business-cycle frequency, while the price level varies erratically. Therefore, *price does not contain all the information about market movements*. Market trends, cyclical periods, and correlation phases have more essential information than the price level for business decision making and macro management. Third, the equilibrium theory of asset pricing offers a misleading recipe for risk management. A diversification strategy works only if market movements have no systematic trends and persistent cycles and all players make independent rational decisions without correlated actions. If business cycles play a leading role in market movements, cash-flow and credit-line management should be the key factor in risk management (CAPM model by Sharp 1964). Investors do not just make a simple choice between stocks and bonds. Cash can become king when uncertainty is pervasive. That is why securitization is not capable of preventing crises such as the sub-prime debacle. On the contrary, complex tools of derivative trading amplify market resonance by leveraging under the guidance of equilibrium theory of arbitrage-free opportunities.

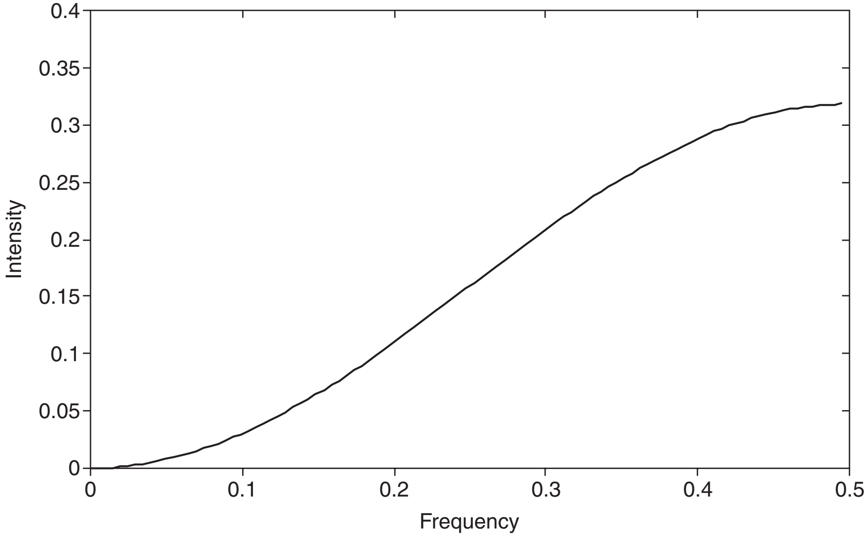

Figure 16.2 The frequency response function for the FD filter.

Notes
Here,

$$FD[S(t)] = S(t+1) - S(t) = \ln\frac{X(t+1)}{X(t)},\ S(t) = \ln X(t).$$

The horizontal axis is the normalized frequency range from zero to 0.5. The vertical axis is signal intensity.

16.2.2 The meso foundation of macro fluctuations and competition policy in the global economy

Lucas (1972) made a strong claim that business cycles could be explained by an equilibrium (rational expectations) mechanism of workers' choices between work and leisure. His microfoundations theory has, however, been rejected by empirical observations based on the Principle of Large Numbers (Chen 2002). It was Schrödinger (1944), the founder of quantum mechanics and quantum biology, who found a salient relationship between the number of micro elements and the variability of aggregate fluctuations.

$$\text{Market variability (MV)} = \frac{STD(S_N)}{Mean(S_N)} \approx \frac{1}{\sqrt{N}} \tag{16.1}$$

The implication of equation (16.1) is very clear. The more micro elements involved, the less will be the aggregate fluctuation. This is the Principle of Large Numbers. This relation holds not only for static aggregation, but for some dynamic systems such as the population dynamics of the birth–death process

(Chen 2002). Empirically speaking, since we can measure MV from aggregate indexes, we can also infer the effective cluster number (ECN), N, at the micro level. Therefore, we have a powerful tool to identify the source of aggregate fluctuations – if there is an explanation for microfoundations (the structual level of households and firms) or an explanation for meso foundations (the structural level of financial intermediates and industrial organization in the form of clusters). The empirical results are shown in Table 16.1.

The number of households, corporations, and public companies and their implied orders of MV in 1980 are given in Table 16.2.

From Tables 16.1 and 16.2, we can see that household fluctuations contribute only about 5 percent of fluctuations in real gross domestic product (GDP) and less than 1 percent in real investment, and small firms can contribute 50 percent of fluctuations in real GDP or 8 percent in real investment, while public companies can generate about 60 percent of aggregate fluctuations in real investment. Clearly, there are very weak "microfoundations" but strong evidence of a "meso foundation" in macroeconomic fluctuations. The doctrine of "too big to

Table 16.1 Market variability (MV) and effective cluster number (ECN) for various aggregate and financial indexes

Item	*MV (%)*	*ECN*
Real personal consumption	0.15	800,000
Real GDP	0.2	500,000
Real private investment	1.2	10,000
Dow Jones Industrial (1928–2009)	1.4	9000
S&P 500 Index (1947–2009)	1.6	5000
NASDAQ (1971–2009)	2.0	3000
Japan–US exchange rate (1971–2009)	6.1	300
US–euro exchange rate (1999–2009)	4.9	400
Texas crude oil price (1978–2008)	5.3	400

Sources: US aggregate indexes and exchange rates are from the Federal Reserve Bank at St. Louis; stock indexes data are from yahoo.finance; the oil price index is from the US Energy Information Administration.

Notes
For nonstationary time series, market variability is measured via the HP filter; the average is estimated from a moving time window in the range of the average length of business cycles, here is proxied at five years (Chen 2002).

Table 16.2 Numbers of households and firms in the United States (1980)

Micro agents	*Households*	*Corporations**	*Public companies*
N	80,00,000	2,900,000	20,000
MV (%)	0.01	0.1	0.7

Source: US Bureau of Census.

Note
* Here, we count only those corporations with more than $100 000 in assets.

fail" might be true at the micro level in the cases of external shocks, but it is not true at the macro level in terms of the meso–macro relationship. This fallacy of composition still misleads equilibrium economists in their representative model of macro behavior.

More surprisingly, the order of market variability in the oil and currency markets is much higher than real investment and the stock market, which indicates the ugly fact of financial concentration generated by giant financial corporations. This is the real root of this Grand Crisis!

Dan Gilligan (2009), President of the Petroleum Marketers Association (PMA), has revealed that financial giants such as Morgan Stanley, Goldman Sachs, Barclays, and JP Morgan were manipulating the oil price. They put hundreds of billions of dollars in the oil futures market, in addition to money invested by large institutional fund managers such as the California Pension Fund, the Harvard University Endowment, and other institutional investors. They started their speculation in 2000, when the US Congress deregulated the futures market, granting exemptions for complicated derivative investments called oil swaps, as well as electronic trading on private exchanges. Volatility in the price of oil increased dramatically. Later in the decade, within one year, the oil price rose from $67 a barrel to $147 a barrel, then collapsed back down to $45. On one occasion, the oil price jumped $25 in one day! Surprisingly, changes in oil demand and supply in this period were less than 5 percent, while changes in the price of oil were larger than 100 percent! From the middle of June to the end of November 2008, when a US congressional investigation started, about $70 billion of speculative capital left the future markets. At that time, demand for oil dropped 5 percent, but the price of oil dropped more than 75 percent to $100 per barrel. Gilligan estimated that about 60–70 percent of oil contracts in the future markets were controlled by speculative capital at the peak. In the past five years, hedge funds and global banks have poured capital into the oil market. Their "investment" rose from $13 billion to $300 billion. Something must be done to stabilize commodity future markets.

16.2.3 Rethinking the theoretical foundation of trend collapse, higher moment risk and the financial crisis in the derivatives market

In the 2008 financial crisis, credit default swaps (CDS) played an important role when the fall of Lehman Brothers generated a tremendous loss for AIG. We suspect that the oversimplified model of CDS options based on orthodox pricing theory played a significant role in ignoring underlying market instability.

An important discovery related to the Principle of Large Numbers is the viable dynamics for sustainable markets. For stochastic dynamics with a growth trend, there exist stochastic models with the distinct feature of market variability (Chen 2002, 2005; Li 2002). Their results are quite enlightening. Random walks are dampening, Brownian motion is explosive, but the birth–death process tends to be a constant in the form of the Principle of Large Numbers. The random walk and Brownian motion are representative agent models by nature. Only the birth–

death process is a population model, which is capable of describing social interaction and collective action in behavioral finance.

It is possible to modify the option-pricing model based on the population model of the birth–death process in stock-price movements (Zeng and Chen 2008). For the representative agent model of geometric Brownian motion, the probability of stock-price movement can be described by a binomial tree (Cox *et al.* 1979). Credit default swap valuation is also based on a similar model (Duffie 1999). For our model in the birth–death process, stock-price changes can be understood by a trinomial tree, in addition to the probability of prices moving up and down, there is a chance of a stable price. This complexity might exhibit the so-called volatility smile (changing market volatility driven by irrational herd behavior in financial market) observed in option prices. A more general model of evolution in probability distribution can be derived in terms of a master equation (Tang 2009). Based on empirical observations, transition probability can be described by a nonlinear function; its solution can be approximated by expansion in terms of higher moments. If we consider only the first and second moment (i.e., mean and variance in portfolio theory), the solution will converge to that of the Black–Scholes model, in which an arbitrage-free portfolio can be constructed. If, however, we add the third and fourth moments, the model solution might produce complex patterns, such as a trend collapse and market crisis (Figures 16.3 and 16.4). In other words, *financial crisis can be understood as higher moment risk.*

The high moments (cumulants) have infinite terms in theory. In practice, we only need to calculate finite moments from the empirical data to judge the

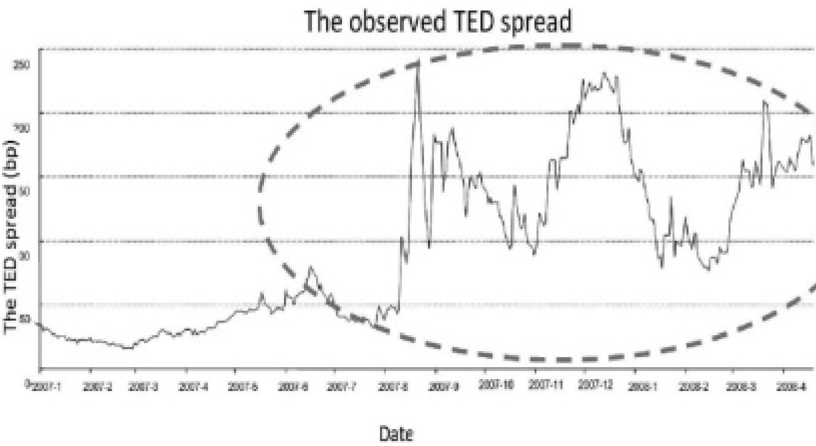

Figure 16.3 The observed TED (three month interest rate spread between eurodollar LIBOR rate and US Treasury bill rate) series (January 2007 to April 2008) (source: www.tedspread.com/).

Note
A dramatic rise of TED signaled the rising risk premium, which is an essential feature of financial crisis.

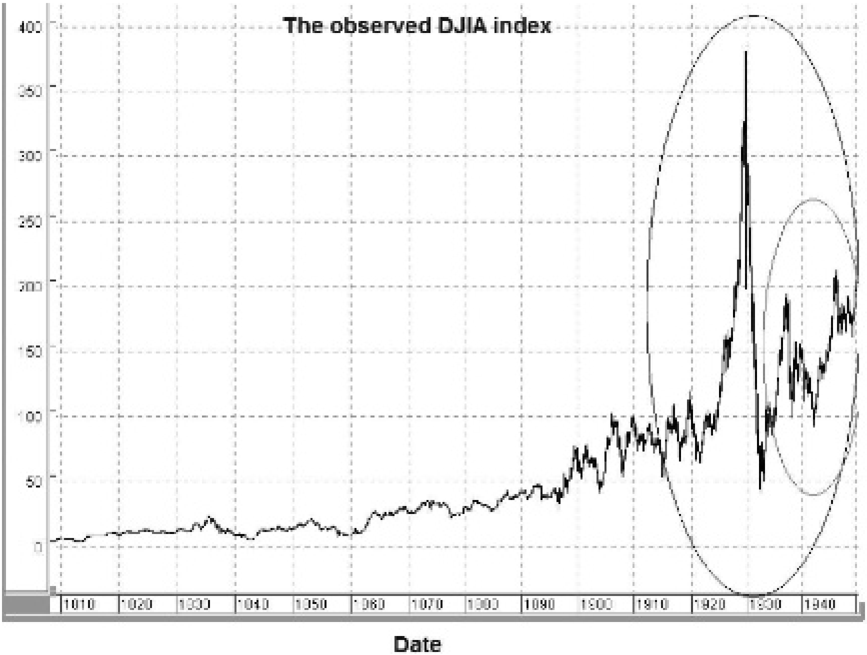

Figure 16.4 The Dow-Jones Industrial Average (DJIA) index during the Great Depression, which has a similar pattern in Figure 16.3 (source: metastcok).

overall pattern in Figure 16.3. We select the second to fifth moments here for a comparison with empirical events (Table 16.3).

Now, we have a better understanding of why the derivative market might collapse on a large scale. When the option-trading mechanism is simple enough, Black could adjust the model parameters such as market volatility so that the theoretical solution could close on the empirical price. In a complicated over-the-counter derivative market with thin market and loose regulation, however, such as the credit default swap market, trading based on an oversimplified binomial-tree model would mislead the market without empirical calibration. This Grand Crisis has provided a striking example of how a linear model for a

Table 16.3 The calculated moments of TED spread

Variance	*Skewness*	*Kurtosis*	*Fifth order cumulant*	…
0.0196	0.4537	2.8378	2.5448	…

Notes
The moments (up to the fifth moment) are calculated with a three day time window from the TED data in Figure 16.5. A clear sign of financial crisis is visualized by a dramatic rise in TED high moments.

complex market can create such a tremendous turmoil. Better alternative models on asset-pricing theory are needed to prevent a similar crisis in the future.

16.2.4 Economic complexity of transaction costs and the selective mechanism of industrial organization

The US administration has long realized the critical role of prudent financial regulation. Mainstream economists, however, still argue that the market can be self-regulating; following the Coase theory of transaction costs. Coase (1937) claimed that the foundation of the firm was the incentive to reduce transaction costs. Coase (1960) believed that social conflicts could be solved via bilateral exchange without interference from a third intermediary such as government or legal action. Coase (1990) claimed that the US financial market was an ideal model of the Coasian world of zero-transaction costs. He seemingly ignored the fact that regulating the financial market has had increasing complexity as well as increasing transaction costs. Coase (1979) challenged the need of regulation when he openly placed doubts on anti-bribery legislation for the media industry. He simply ignored the social costs that emerged when bribery and market manipulation generated system instability, which could potentially cost much more than regulation. The real aim of the Coase theory was to reject antitrust policy when he was ignored at his first meeting with the Chicago school, which forced him to change his vocabulary from competitive monopoly to transaction costs (Kitch 1983). This study revives the old debate about antitrust policy from the new perspective of market instability and economic complexity.

Coase is wrong simply because he ignored the issue of economic complexity (Chen 2007a). A firm's driving force is value creation, not transaction costs reduction. Innovation creates both instability and complexity that are sources of increasing transaction costs in division of labor. Bilateral exchange cannot solve conflicting interests in pollution and market manipulation because there is no increasing demand for negative externality. Government regulation and people's participation is essential in maintaining orderly market and resolving social conflicts. Whether regulation is proper or not, it cannot be judged by transaction costs in the short term, but by social effects in the long term. Coase theory is another type of perpetual motion machine without heat (i.e., transaction costs) dissipation, which is against the second law of thermodynamics. The simple fact of global warming is a clear case of increasing energy consumption and dissipation, which is a strong evidence of increasing transaction costs during industrialization. China could avoid a financial crisis mainly because its policy is selectively open to constructive FDI, not speculative hot money.

16.2.5 The danger of Friedman's theory of exogenous money and the tri-polar world of the Great Depression

So far, the weak effect of expansionary monetary policy reminds us of the danger of the exogenous theory of business cycles, discussed previously. The current monetary policy adopted by mainstream economists is strongly influenced by Friedman's theory of exogenous money and his misleading explanation of the Great Depression (Friedman and Schwartz 1963). Friedman assumed monetary movement was exogenous, so central bankers' monetary policy had no historical or structural constraints. The discovery of monetary chaos challenged the monetarist theory of exogenous money but supported the Austrian theory of endogenous money (Chen 1988a, 2005). Few economists, however, realized the danger of monetarist policy in dealing with economic crises such as the failure of the Washington consensus, crises in Latin America and East Asia, and the Transition Depression in EEFSU (Chen 2006, 2008).

Friedman claimed that expansionary monetary policy alone could have prevented the Great Depression, though there is no solid empirical evidence to support his theory. It would be very dangerous for central bankers around the world to follow Friedman's simple-minded theory in dealing with the current crisis with deep social and geopolitical roots.

On the contrary, we have abundant evidence supporting the Austrian theory of endogenous money. In 1998, China had to confront severe deflation in the aftermath of the East Asian financial crisis. China managed to maintain sustained growth mainly through fiscal policy – manifest in large investments on infrastructure. So far, we already see that the effectiveness of monetary policy is highly constrained by historical policy and economic structure. When the business sector is heavily in debt, expansionary monetary policy can move only short-term interest rates and might be powerless to determine medium and long-term interest rates when investors feel uncertain about the economic outlook due to the danger of deep recession, possible inflation, and currency depreciation. Since late 2008, major countries have rapidly adopted crisis policies such as monetary expansion, fiscal stimulus, and enhancing regulation in the financial market, including setting limit to executive pay and financial leverage. From our observation, the US administration has tried only to treat the symptoms rather than to cure the American disease, which is the huge power of the financial sector to crowd out the industrial sector. So far, we see no attempt by policy makers to break up monopolistic financial firms such as AIG and Citibank. Thinking strategically, we should prepare for the worst scenario and then work out the best solution.

Kindleberger (1986) has produced a highly relevant analysis that is helpful in understanding the current crisis. Friedman believed that the Great Depression was triggered by one simple event: the death of New York Federal Reserve Governor, Mr. Strong, which left a vacuum in the Fed's monetary policy. Kindleberger pointed out that the global depression was caused by the collapse of globalization based on British leadership. The three world powers after World War I – the United Kingdom, the United States, and France – were kicking the ball among themselves and eventually provoked a collapse in the whole global system. We have a similar situation today, since the United States has lost its automatic world leadership via excessive military expansion and excessive consumption. The world order has changed since the 1980s; unless the United

States, Europe, and China coordinate their efforts, we could face an international situation discussed by Kindleberger on the international cause of the Great Depression before the 1930s.

What is the worst situation that might result from this Grand Crisis? Japan's stock market and real estate crisis of the 1990s lasted more than a decade. US President Roosevelt's "New Deal," including Keynesian policy in fiscal stimulus and welfare policy, did not end the Great Depression, which lasted for 11 years until World War II. There may be little chance of World War III among the major nuclear powers; however, the next wave of government defaults could destabilize small countries, worsen existing wars in the Middle East, and intensify regional and ethnic conflicts in South Asia and Africa. The possibility of a regional nuclear war should not be fully discounted.

The best case scenario is that current globalization can be stabilized. This is possible only if trust in security matters and financial coordination can be consolidated among the major military and economic powers, including the United States, the European Union, China, Russia, and Japan. The cold war did not turn into a "hot war" since the Yalta bipolar structure was stable during the cold war era. Since the Soviet Union dissolved, the unipolar structure based on US dominance is significantly unstable in a world of disequilibrium with increasing disparity between rich and poor countries.

16.3 China's development and a changing world order

The current Grand Crisis accelerates the demand for reforming international financial order. To reach a realistic goal, we should first analyze the deep sources of this global financial crisis, then evaluate possible scenarios, before taking a collective action.

16.3.1 The American disease and the China puzzle

Before discussing China's role, we need to understand the world today from an evolutionary perspective. Bernanke once suggested that the US imbalance was rooted not in excessive consumption but in China's excess saving. I have a different view on this. The United States is much more powerful than China and the other Asian economies combined. Its financial power still dominates the international financial order – as we already know from the foregoing discussion.

The United States' trouble in the financial markets began with former President Ronald Reagan's contradictory economic policies in the 1980s. On the one hand, Reagan launched a tremendous military expansion; on the other hand, he provided substantial tax cuts and deregulated the financial sector. Growing public debt financed the budget deficit that resulted, which drove up interest rates and the dollar, and ruined the competitiveness of the US manufacturing industry. As we know, the response to this was outsourcing – first to Japan and then to East Asia. The United States pushed Japan to appreciate the yen, but that did not solve its trade deficit. Instead, it threw the manufacturing industry out of Japan and to the "Asian tigers" and mainland China. Since then, the United States has been putting pressure on the Chinese government to appreciate its currency without much success.

In fact, Chinese economists and governments did realize the danger of overexposure to the American financial market. The difficulty is to find a safe exit. China did some experiment in the first half of 2008 by raising the interest rate, exchange rate, and minimum wage simultaneously. Some economists believed that monetary policy alone could easily push structural changes. But waves of bankruptcy of manufacture firms in coastal areas rose strong opposition from local governments, so that central government had to adjust its policy just in time before the financial crisis reached the Chinese economy in the second half of 2008. After experiments, Chinese leaders could better tell the different effects among monetary, fiscal, and industrial policies. Certainly, China alone could not solve the imbalance both in domestic development and international market. Further dialogue among major trading partners is critical to solve the current crisis.

The United States' fundamental problem is that the financial sector has replaced the industrial sector as the driver of its economy. You cannot cure that disease by playing currency or monetary games. Since the 1970s, no matter how the exchange rate has fluctuated, the United States has had a persistent trade deficit, while Germany and Japan have had a persistent trade surplus. This imbalance has little to do with short-term exchange rate adjustment, but much with US long-term strategic policy. The United States still has advanced technology and abundant resources, but continues to waste immense resources on military spending and financial speculation. What is needed is a fundamental change in its policy framework.

As for China, of course it has to adapt to US foreign policy, but it has also benefited from its short-sighted strategy. During the East Asian financial crisis, China followed the United States' recommendation that it should not devalue its currency. Before and during that crisis, mainstream American economists had one single policy recommendation for Latin America, Hong Kong, and China: dollarization, dollarization, and dollarization! Remember that most Chinese reformers tried very hard to learn about the market economy from US textbook economics. They all lectured that US Treasury Bonds are a risk-free investment compared with risky stocks and corporate bonds. The Chinese government therefore decided to target China's exchange rate with the dollar and buy US Treasury securities. This was thought to be the best way to preserve the value of Chinese savings – or at least a much better way than to invest them on China's own enterprises. Once China chose that road, however, US Treasuries turned out to be a trap. In such a situation, China had fewer options than Japan and European countries in the currency game, because of the asymmetrical policy adopted by the United States. When the dollar goes down, Japanese or Europeans can buy US assets, but Chinese cannot – blocked as they are by the United States' national security policy. At the same time, American and other foreign banks and firms are invited to be strategic partners with China's state-owned firms for improving China's competitiveness. Does the United States think that China is less sensitive to her security interests than to US? China's increasing confidence in its self-determined open-door policy lies in its increasing competitiveness and learning ability, not in the old-fashioned protection policy.

I would still claim that this asymmetrical trade policy has in fact done more good for China than for the United States in the changing world balance. US administrations have repeatedly used political pressure in exchange rate policy. It did not resolve the US deficit problem, but it did accelerate the economic integration of East Asia. How did that happen? If world trade were free and based on rules of symmetry, China would be buying much more US technologies than it really does. Since the United States does not allow exports of high-tech products to China, China can import only second-hand technology. The United States does, however, export high technology to Japan and other East Asian countries, and this preferential trade policy has created an arbitrage opportunity for these countries. It is not by accident that, since the 1980s, China has had a persistent trade deficit with Japan, then with South Korea and with Southeast Asian countries. In fact, these deficits are quite comparable with China's trade surplus with the United States. What does this mean? It means that the United States has given away a huge trade opportunity to China's neighbors for geopolitical rather than economic purpose.

Historically, US policy of China containment during the cold war might delay China's peaceful development of market economy, but did stimulate China's strategic investment in education, infrastructure, basic research, and strategic industries, which is also part of China's comparative advantage in global competition. Chinese philosophy has learned how to prepare for harsh adversaries mainly by strategic moves and united effort rather than by military or monetary power.

What, however, are the real results of this policy? After the East Asian financial crisis, all these countries realized that China was a more reliable partner in international trade than previously thought, since China did not devalue its currency despite the crisis. They also realized that their economies benefited greatly from China's rapid growth. So, geopolitically speaking, these countries went from being insecure neighbors to Chinese partners. South Korea, the members of the Association of South-East Asian Nations (ASEAN) countries, and Vietnam, in addition to Hong Kong and Taiwan, became increasingly integrated in the rapidly growing Chinese economy.

Today, East Asia is the third largest economic zone in the world, with relatively stable exchange rates to the dollar, which also helps to stabilize the US currency. If US policy makers realize that this can be the basis for closer economic cooperation, I would say that our future is bright. If, however, the United States considers this a challenge rather than an opportunity, it signals a troubling future.

This is the geopolitical heritage of the Reagan regime and the US imbalance. So far, the United States is still able to maintain its financial power in spite of increasing deficits. One critical factor in this is China's exchange rate policy. So far, both Chinese and Americans are happy about the past but worry about the future. Unlike her Asian partners, China does not get any credit from US policy makers. Perhaps the United States should think about how to win other people's trust rather than just financial interests. And China should pay more attention to new opportunities beyond the American market.

We need to explain one of the "China puzzles": why China has a much higher saving rate than industrialized countries – or why do poor countries end up subsidizing the rich ones such as the United States? Some Western observers speculated that China's rapid growth was not based on technological progress and organizational innovation but on suppressing workers' wages and thus household consumption. They claim, therefore, that appreciation of the Chinese currency will not only solve the United States' problem of a persistent trade deficit, but also stimulate the consumption and welfare of the Chinese people. Is it that simple?

My observation is that China's high savings are the result of asymmetrical power in the credit market and marketing networks, since nonlinear pricing is the main tool used by the multi-national companies that dominate China's export market. More than half of China's exports are by foreign firms – and most export channels are controlled by multi-national firms such as Wal-Mart. Chinese companies and the Chinese government has no pricing power in the international market. For any Chinese product sold in the United States, Chinese companies receive 2–5 percent of the sale value. As a result, China's domestic market is more open and more competitive than those of the United States, Japan, or any other country in Asia and Europe. If we look, for instance, at China's car industry, we see that the market, unlike in the United States, is not dominated by the "big three"; there are more than 100 companies competing with each other. Their profit margins are very thin compared with their giant foreign competitors. In order to survive, they have to upgrade their technology mainly through self-financed investment. Small and medium firms have little access to the stock or bond markets. The underdeveloped financial market and marketing network leads to a very high saving rate in Chinese firms prepared for market uncertainty. China needs more bold experiments in developing financial innovation, which should aim to develop small and medium firms for creating jobs rather than for reducing transaction costs or maximizing short-term profits.

Since China launched its reforms some 30 years ago, its annual growth rate in residential income and consumption has been about 7 and 6 percent, respectively. China's high saving puzzle cannot be explained by households; it has to do with the behavior of firms. If we look at the composition of China's immense bank deposits, the deposits of individuals represent some 50 percent, with more than 30 percent coming from firms. If there is so-called excess saving, China's domestic interest rate should be even lower than those in the United States. In fact, China's interest rate in the domestic market is much higher than that paid on US Treasuries. In rural industries, the gray-market interest rate is more than 20 percent. Clearly, strong market competition leads to strong competition in investment in technological upgrading among all industries and firms. The Chinese government has very limited means to cool investment since public investment is much smaller than private investment. Certainly, regional governments have strong incentives to preserve manufacturing industries for job creation and revenue stability.

I would guess that if the US government adopts new antitrust laws and breaks up monopolistic firms, as it did with AT&T, US industries will become more competitive. Both US firms and households will behave more like Chinese – investing on technology and education rather than on money game, big houses, and big cars. In the end, you would see more balanced trade in the world market.

Bernanke points out China's high saving rate, rather than the low saving rate in the United States, as a possible source of financial instability. We might ask a more fundamental question about the driving force of growth: should it be consumption, exploitation, new technology, or new industry? From long-term perspective, supply-side innovation rather than demand-side consumption should be the very foundation of sustainable growth.

Let's assume that one country spends most of its income on consumption, while another country spends more on innovation. Which country do you think will win the international competition? That's a very simple question – no matter what natural resources and property rights we take into account. You don't need a grand theory; commonsense will do to answer this simple question. I would suggest that China could better direct public and private savings to more investment in education, health care, and water conservation that would pave the future foundation of sustainable development.

One critical lesson from this American-made crisis is that technology leadership and market dominance alone in private sector is not sustainable without social support from public sector. The big three auto companies are near bankruptcy because of the high social costs. "Each car in Detroit carried about $1,400 in extra pension and health-care costs compared with the foreign-owned competitors in America." The averaging medical costs in the US are twice of European countries and Canada, and three times of Japan (*The Economist* 2009b). China should learn more from the mixed systems of pension and health care in Europe, Japan, and Scandinavian countries rather than the dominating private system in the US.

16.3.2 China's realistic role in a changing world order

There is much debate about China's role in a changing world order – from the "China threat" to "G2" status. As a personal observation, China's success is based on a decentralized experiment in searching for a Chinese model of global competition. There are several features of the Chinese system that are different from mainstream economics based on the Anglo-Saxon model – so-called laissez-faire economics.

First, China has been a unified country since 200 BC – formed not by market forces but by political organization based on a small-scale, self-sufficient economy. China has only 10 percent arable land, and has experienced frequent wars and natural disasters. Historically, there has been persistent demand for effective governments rather than small governments. China developed resource-saving but labour-consuming technology while the West developed labour-saving but resource-consuming technology under different ecological conditions (Chen 1990, 1993b). The Chinese model is therefore different from the Western model because there is a trade-off between stability and complexity (Chen 2005). This implies that developing countries should explore technologies appropriate to them and develop effective government to meet historical challenges. There is no universal recipe to fit a diversity of situations.

Second, China's shift of its development basis from inland to coastal areas was based on a strategic evaluation of the changing world order. The Korean War, the Vietnam War, and the United States' policy of containment forced China to channel domestic savings into building up its defense industry and technological foundation. When US interest shifted to the Middle East, Deng Xiaoping's open-door policy seized the opportunity and developed the coastal economy, which became the engine of China's technological progress and export-led growth. China's competitiveness is not based on cheap labor, but on an effective welfare system and well-developed technology base. Four-fifths of the population live on collectively owned land without paying expensive social security taxes. China's main strength lies in his human capital. A large number of engineers and scientists were trained in Mao's era. China's effort in transforming defense industry into civilian industry is more successful than the United States and EEFSU, which was a lesson learnt from the rise of Germany and Japan after World War II and other Asian tigers. That is why China's open-door policy did not create a dependent economy; simply because China's domestic industry could rapidly learn and compete with multi-national companies. Cheap labor alone never leads to take-off in developing countries. In contrast, land and asset privatization in EEFSU led to a significant decline in agricultural and industrial output, a rapid increase in income inequality, and a breakdown of the social welfare system. The economic costs of the Transition Depression in EEFSU were even heavier than two world wars and a civil war in Russia in the 1920s (Chen 2006).

Third, China is still a developing country with large regional disparities and tremendous population pressures under limited resources. Small and medium firms engage in the export market, mainly because market channels in the domestic market are far behind those in industrialized countries. It would be naive to demand that the Chinese currency ascend to reserve currency status, which could lead to premature liberalization of the capital account. From international experience, Germany has more rigorous regulation of its financial market, so that German industry has firm support from the financial sector, while Japan wrongly accepted US advice in liberalizing its financial market and lost a decade. China's policy makers should be careful in learning and experimenting in adopting the international financial market.

We suggest that China could learn more from other countries and play a constructive role in the global arena.

First, the European Union grew out of the European Coal and Steel Community in 1951, when France and Germany became partners instead of rivals. If China, Japan, South Korea, and the ASEAN countries could build up a similar economic program – such as the joint development of offshore oil reserves – East Asia could integrate into an Asian union. Political wisdom with long-term vision is needed for Asian leaders in facing the current crisis. In Chinese, "crisis" (*wei-ji*) implies both danger (*wei*) and opportunity (*ji*). The Japanese, South Korean, and Chinese populations are aging; therefore, there is diminishing chance of military conflict but increasing desire for economic cooperation among them. Even if US-led globalization falls apart, East Asia could still maintain a stable and healthy regional economy. In doing so, other countries might join the East Asian community, including Australia, New Zealand, Russia, India, and the Pacific United States, so that a better name in the future might be the "Pacific Union," in parallel with the European Union and North America free trade zone. The next phase of globalization would then have a tripartite regional foundation that would be more competitive and cooperative than the existing US-led globalization.

Second, the euro, yen, and renminbi cannot yet displace the US dollar. The financial innovation of the "euro dollar" market was created in 1957 by the Soviet Union and British banks in order to get around the controls of US financial power. Growing US deficits led to rapid expansion of the euro dollar market. In the current Grand Crisis, European banks have experienced heavy losses, caused by the US sub-prime crisis. This in turn has hurt South Korea, Brazil, Russia, and other developing countries, as they have lost money on deposits in the euro dollar market. China could cooperate with other Asian countries to develop an "Asian dollar" market for sovereign debts, since China could constructively utilize its excess foreign reserves. Currency and sovereign bond swaps can be integrated into the Asian dollar market, increasing its depth and sophistication over time. If the US Federal Reserve printed too much money, thereby destabilizing the global economy, higher uncertainty would raise interest rates in both the euro and Asian dollar markets that would cause capital flight from the US financial market. Market forces would effectively discipline central bankers if their monetary policy was irresponsible or near-sighted. Goodwill alone is not a sufficient condition for a sound international order. International competition is a necessary condition for international stability.

Third, China's recent investment in foreign natural resources has caused a series of public relations problems since China's operation of state-owned enterprises (SOEs) is not compatible with Western laws and conventions. China should learn from the US model of land-grant universities and non-profit university endowment funds, rather than the Singaporean model of sovereign wealth funds. SOEs transformed into publicly listed, shareholder companies owned by university funds, pension funds, and so on, would greatly improve China's image abroad and its educational foundation at home. Currently, China's technological attainment depends heavily on foreign technology. China's higher education system is essentially a teaching rather than a research system. By dividing state assets among a dozen or so competitive "land-grant" university endowment funds, China could build up a strong system of innovation by integrating research, education, and production. Western media could easily understand the nature and objective of a Peking University Fund or Fudan University Fund along the lines, for example, of the Texas University Fund and Columbia University Fund as qualified investment institutions.

Fourth, large holdings of American government debt are not a sound investment both for China and the US, since subsidizing American excess consumption and military expansion is not sustainable. However, China could diversify her currency risk and increase goodwill among American people by encouraging cross investment between regional governments. For example, the state of California has tremendous human resources but huge financial stress in this crisis. They simply had no money to repair poor bridges or hire university scientists. I would like to suggest that Shanghai city government could help California by buying California state bonds in exchange for long-term cooperation between the California State University System and the Shanghai higher education system. China's regional governments are very innovative in not only advancing local industry but also developing human networks for win–win competition.

16.3.3 Basic considerations in reforming the international financial market

Based on the above discussion, there are some basic considerations for reforming the international financial market.

First, current economic and financial bureaucracies are heavily influenced by equilibrium economists and financial interests. It would be helpful to establish a non-governmental expert forum under the United Nations; their policy recommendations could be more constructive for discussions among world leaders.

Second, regulation and supervision should center on an international competition or antitrust policy. The market shares of giant financial companies in the commodity market, currency market, and some key financial sectors should be subject to an upper limit, such as 5 percent. Trading volume should be monitored frequently and transactions above a certain threshold should be reported and regulated.

Third, a Tobin tax on currency and commodity exchanges is essential to protect small countries without large amounts of foreign reserves. Tobin tax receipts should be housed in a specific development fund for helping developing countries. Debt equity swap under strategic agreement may increase mutual trust and ease market anxiety about financial uncertainty.

Fourth, each country has the sovereign right to match its exchange rate regime to its development stratagem. Its exchange rate can be linked to SDR (Special Drawing Rights), a reserve assets created by IMF calculations with gradual adjustment every five years or so. An economic council under the United Nations, which is responsible for coordinating major countries in stabilizing their exchange rates, could regulate the IMF. An orderly adjustment of exchange rates could be conducted every five years or so except in emergency situations.

Fifth, an overhaul of financial theory and financial regulation would speed up the academic debate about rethinking economic history and theory (Chen 2008). This conference on China's new place in a world in crisis is a small step toward this direction.

16.4 Conclusion

This Grand Crisis is deeply rooted in the new classical counter Keynesian revolution in mainstream economics and Reagan revolution in deregulating market and dismantling the role of governments in managing business cycles. Their main results were concentration of financial power and explosion of market instabilities. To recover the damage and to prevent the next crisis, we must take collective actions among major economies in breaking monopoly powers and enhancing market regulations, so that market forces could advance innovations for majority people, rather than generate destructions for few greedy. We also need to change the linear equilibrium thinking and learn complex evolutionary perspective in a changing world order. Future generations of political leaders and economic students would learn a better lesson from this Grand Crisis.

Let us work together for a better future.

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Epilogue

What went wrong with economics?

> A clash of doctrines is not a disaster – it is an opportunity.
>
> (Alfred Whitehead 1925)

In a recent lecture at the London School of Economics, Paul Krugman, the 2008 Nobel Laureate in economics, said that "most work in macroeconomics in the past 30 years has been useless at best and harmful at worst" (*The Economist*, 2009a). One week later, *The Economist* magazine organized a cover story "What went wrong with economics," discussing major debates in macroeconomics and financial economics.

In a dramatic event, the British Queen visited the London School of Economics in November 2008. She asked why so few economists had noticed that a credit crunch was on its way. The British Academy called a forum in June 2009 and wrote a formal reply on July 22nd. Two Fellows of the British Academy, Tim Besley at the London School of Economics and Peter Hennensey at the University of London summarized the main findings from 33 participants including experts from academia, business, government, and regulators (2009). They listed many causes contributed to this financial crisis, especially the "failure to understand risk as to the system as a whole" and "a psychology of denial" (of market instability). However, another ten leading British and Australian economists led by evolutionary economist Geoffrey Hodgson at the University of Hertfordshire voiced a minority view against the mainstream explanation by the British Academy (2009). In their separate letter to the British Queen, they called for a fundamental reform in training economists. They blame the blind trust in market forces and financial innovations that were deeply rooted in economic education. Mathematic models with a "highly questionable belief in universal rationality and the efficient market" led economic students to be detached from the real world. In the US, Simon Johnson, the former chief economist at IMF and current MIT professor, argues that the root of the financial crisis to be that the US government was captured by financial oligarchs, and that breaking financial oligarchs apart is the only way out of this recession (2009).

In the face of the waves of criticism, Robert Lucas, the 1995 Nobel Laureate in economics at the University of Chicago, rebuts criticisms in a guest article

(*The Economist*, August 6, 2009). His article is republished here at the permission of *The Economist*. We ask our readers to read the Lucas defense first, and then conduct our analysis with what went wrong with Mr. Lucas, the best example of current mainstream thinking. For the reader's convenience, we use italics for the original statements from Robert Lucas.

Robert Lucas (2009): "*In defense of dismal science*"

There is widespread disappointment with economists now because we did not forecast or prevent the financial crisis of 2008. The Economist'*s articles of July 18th on the state of economics ("What went wrong with economics,"* Economist *2009b) were an interesting attempt to take stock of two fields, macroeconomics and financial economics, but both pieces were dominated by the views of people who have seized on the crisis as an opportunity to restate criticisms they had voiced long before 2008. Macroeconomists in particular were caricatured as a lost generation educated in the use of valueless, even harmful, mathematical models, an education that made them incapable of conducting sensible economic policy. I think this caricature is nonsense and of no value in thinking about the larger questions: What can the public reasonably expect of specialists in these areas, and how well has it been served by them in the current crisis?*

One thing we are not going to have, now or ever, is a set of models that forecasts sudden falls in the value of financial assets, like the declines that followed the failure of Lehman Brothers in September. This is nothing new. It has been known for more than 40 years and is one of the main implications of Eugene Fama's "efficient-market hypothesis" (EMH), which states that the price of a financial asset reflects all relevant, generally available information. If an economist had a formula that could reliably forecast crises a week in advance, say, then that formula would become part of generally available information and prices would fall a week earlier. (The term "efficient" as used here means that individuals use information in their own private interest. It has nothing to do with socially desirable pricing; people often confuse the two.)

Mr. Fama arrived at the EMH through some simple theoretical examples. This simplicity was criticised in The Economist*'s briefing, as though the EMH applied only to these hypothetical cases. But Mr. Fama tested the predictions of the EMH on the behaviour of actual prices. These tests could have come out either way, but they came out very favourably. His empirical work was novel and carefully executed. It has been thoroughly challenged by a flood of criticism which has served mainly to confirm the accuracy of the hypothesis. Over the years exceptions and "anomalies" have been discovered (even tiny departures are interesting if you are managing enough money) but for the purposes of macroeconomic analysis and forecasting these departures are too small to matter. The main lesson we should take away from the EMH for policymaking purposes is the futility of trying to deal with crises and recessions by finding central bankers and regulators who can identify and puncture bubbles. If these people exist, we will not be able to afford them.*

The Economist*'s briefing also cited as an example of macroeconomic failure the "reassuring" simulations that Frederic Mishkin, then a governor of the Federal Reserve, presented in the summer of 2007. The charge is that the Fed's FRB/US forecasting model failed to predict the events of September 2008. Yet the simulations were not presented as assurance that no crisis would occur, but as a forecast of what could be expected conditional on a crisis not occurring. Until the Lehman failure the recession was pretty typical of the modest downturns of the post-war period. There was a recession under way, led by the decline in housing construction. Mr. Mishkin's forecast was a reasonable estimate of what would have followed if the housing decline had continued to be the only or the main factor involved in the economic downturn. After the Lehman bankruptcy, too, models very like the one Mr. Mishkin had used, combined with new information, gave what turned out to be very accurate estimates of the private-spending reductions that ensued over the next two quarters. When Ben Bernanke, the chairman of the Fed, warned Hank Paulson, the then treasury secretary, of the economic danger facing America immediately after Lehman's failure, he knew what he was talking about.*

Mr. Mishkin recognised the potential for a financial crisis in 2007, of course. Mr Bernanke certainly did as well. But recommending pre-emptive monetary policies on the scale of the policies that were applied later on would have been like turning abruptly off the road because of the potential for someone suddenly to swerve head-on into your lane. The best and only realistic thing you can do in this context is to keep your eyes open and hope for the best.

After Lehman collapsed and the potential for crisis had become a reality, the situation was completely altered. The interest on Treasury bills was close to zero, and those who viewed interest-rate reductions as the only stimulus available to the Fed thought that monetary policy was now exhausted. But Mr Bernanke immediately switched gears, began pumping cash into the banking system, and convinced the Treasury to do the same. Commercial-bank reserves grew from $50 billion at the time of the Lehman failure to something like $800 billion by the end of the year. The injection of Troubled Asset Relief Programme funds added more money to the financial system.

There is understandable controversy about many aspects of these actions but they had the great advantages of speed and reversibility. My own view, as expressed elsewhere, is that these policies were central to relieving a fear-driven rush to liquidity and so alleviating (if only partially) the perceived need for consumers and businesses to reduce spending. The recession is now under control and no responsible forecasters see anything remotely like the 1929–33 contraction in America on the horizon. This outcome did not have to happen, but it did.

Not bad for a Dark Age

Both Mr Bernanke and Mr Mishkin are in the mainstream of what one critic cited in The Economist*'s briefing calls a "Dark Age of macroeconomics." They are exponents and creative builders of dynamic models and have taught these "spectacularly useless" tools, directly and through textbooks that have become industry standards, to generations of students. Over the past two years they (and* *many other accomplished macroeconomists) have been centrally involved in responding to the most difficult American economic crisis since the 1930s. They have forecasted what can be forecast and formulated contingency plans ready for use when unforeseeable shocks occurred. They and their colleagues have drawn on recently developed theoretical models when they judged them to have something to contribute. They have drawn on the ideas and research of Keynes from the 1930s, of Friedman and Schwartz in the 1960s, and of many others. I simply see no connection between the reality of the macroeconomics that these people represent and the caricature provided by the critics whose views dominated* The Economist*'s briefing.*

When I got the early released version of the Lucas defense on August 6, 2009, I immediately posted a comment at the Lucas Roundtable at *The Economist* on August 7, 2009, which is ranked number one by reader's recommendation (Chen 2009b). Robert Lucas is considered one of the greatest macroeconomists after Keynes. A dialogue with Lucas will help us to clear the clouds in economic thinking. The following is my comments at the Lucas Roundtable with further minor modifications and elaborations.

Ping Chen's comments to "In defense of the dismal science" by Robert Lucas

The Lucas defense of dismal science is vividly contrasted with the sharp criticism by Simon Johnson, the former IMF chief economist, and the painful assessment by Paul Krugman, a Nobel Laureate in 2008.

Lucas was silent about the major questions, which were brought about by the current crisis: what is the nature of this financial crisis, what is the role of government in macro management, and which school of thought should be responsible for economics' ill prevention and preparation for crisis.

Lucas has been the leader of the so-called counter Keynesian revolution under the banner of rational expectations and microfoundations since the 1970s. According to his simplistic but elegant theory, unemployment is the worker's rational choice between work and leisure even during the Great Depression. The source of business cycles is uncorrelated external shocks in nature. There is little room for government intervention, since the market system is inherently stable and rational expectations will defeat government interference. Lucas made his name mainly by modeling technique in macro stochastic dynamics, whose main merit is mathematical simplicity and theoretical convenience, but not economic reality. In policy arena, Lucas effectively turned the linear technique into a rational belief, which was the very foundation of "mistaking beauty for truth" (Krugman 2009).

We found out that the Lucas theory of microfoundations had weak evidence under the Principle of Large Numbers (Chen 2002). This financial crisis gave a historic blow to his microfoundations theory, since the financial crisis was rooted not from microfoundations at a household level, but meso foundation, i.e., the financial intermediate itself. There is little motivation of voluntary unemployment during the depression, since few American households have enough savings to cushion the lost income in an uncertain period. The Great Depression and the current crisis show clearly that the financial market is inherently unstable, as many economists realized a long time ago, including Schumpeter, Hayek, Keynes, Minsky, and behavioral economists, but marginalized by the so-called new classical macroeconomics led by Lucas. Lucas had no courage to defend his theory of microfoundations, but tried to shift the debate from macroeconomics to financial economics, so that he could still play the magic device of ration expectations.

Surprisingly, Lucas claimed that the current crisis even strengthened the credit of the efficient market hypothesis (EMH). His argument was that no one could make a short-term forecast of crisis and make a profit from the right forecast. Mr. Lucas seems to have more belief in laissez-faire economics than his mathematical knowledge of financial theory.

The fundamental assumption behind EMH is that the financial market is ruled by random walks or Brownian motion (Fama 1970, 1991), which is also the very foundation of portfolio diversification strategy and theory of option pricing. The godlike claim of "prices reflecting all available information" is only a simple mathematical assumption of an error term with zero mean in stochastic modeling. If this theory is true, then it is very unlikely that large correlated price movements occur, like the boom–bust cycle or a financial crisis. Eugene Fama, the founder of EMH, himself realized the limit of regression analysis in econometric tests. EMH is not capable of proofing or rejecting any nonlinear models of business cycles. New tools in complexity science reveal better alternatives to the Brownian motion model behind EMH. We had solid evidence of persistent cycles dominating the financial market, which is endogenous and chaotic in nature (Chen 1996a). The sub-prime crisis was started by underestimating risk by rating agencies and excess risk-taking by over-paid executives in the financial market. Housing bubbles emerged by investors failed to realize the changing price trend under the Fed's monetary policy, a typical failure of rational expectations. Diversification strategy does not work when persistent cycles amplify irrational herd behavior or waves of optimism and pessimism. Financial engineering such as credit swaps would fail if the trading strategy follows a wrong theoretical model of geometric Brownian motion, which was explosive in nature (Chen 2005).

When Lucas argued that "If an economist had a formula that could reliably forecast crises a week in advance, say, then that formula would become part of generally available information and prices would fall a week earlier." He did not know that linear thinking ruled out several possibilities of price-falling mechanisms in real economy. If the price-fall triggered by the Lehman failure was perceived as an accidental event as described by EMH and rational expectations, it would not change the market confidence and the stock prices should quickly return to normal by arbitrage activity. In fact, even Lucas acknowledged that the market response was "fear-driven" (a nonlinear social action within the market mechanism as Keynes pointed out before). When the Fed and Finance Ministry failed to intervene, waves of selling off led to market squeezing (a nonequilibrium phenomenon). The price movements are no longer random or short-correlated. Irrational expectations may change price trend and market fundamentals (Soros 2003). Lucas' description of the Fed's actions was clearly a nonlinear process with two stages (before and after the Lehman failure) while the Fed's intervention was over-cautious or over-reacted. Lucas himself told us a vivid story, which contradicts the picture of random walk in the financial market and monetary policy. The essence of EMH and rational expectations is the unique stable equilibrium for market movements. Arbitrage activity would quickly restore market equilibrium without the need for interference from the Fed and Finance Ministry. Lucas was just like Paulson and Bernanke during the ongoing crisis in that they did not fully know what they were doing and how the market would change.

There is abundant evidence from numerous crises before that asset prices may not reflect all relevant information, or even worse, that asset prices may distort relevant information by greedy investment bankers (Fang 2004). Robert Shiller warned of the danger of inflated housing prices before the housing market meltdown (Shiller 2005). The difficulty in the short-term forecast of a financial crisis has nothing to do with market efficiency. The empirical evidence of nonlinearity and complexity widely exists in the financial market. Simple mechanisms, such as over-reaction and delayed feedback, would generate deterministic chaos, which imposes a limitation on trajectory forecast but increases volatility of price movements (Chen 1988a). Financial leverage plays a key role in generating boom–bust cycles (Semmler and Bernard 2009).

Lucas was too early to name Frederic Mishkin and Ben Bernanke as model students of the dynamic general equilibrium model, the main tool of the Dark Age macroeconomics. Technically speaking, they can always explain observed time series by introducing enough shocks and lags in linearized models (Lucas 1972; Bernanke *et al.* 1999). The general equilibrium framework abstracts away market instability, which does not go away in reality (Galbraith 2009). When Simon Johnson's criticism of America's oligarchs and their capture of the government's rescue policy, Lucas seems satisfied by the Fed's unconventional monetary policy. They all ignore the system risk and conflicting interests between the financial and real sector, a scenario certainly missing in the Dark Age macroeconomics and financial economics.

Mr. Lucas did raise a fundamental issue in laissez-faire economics, when he declared:

> *The main lesson we should take away from the EMH for policymaking purposes is the futility of trying to deal with crises and recessions by finding central bankers and regulators who can identify and puncture bubbles. If these people exist, we will not be able to afford them.*

This is the new version of the Lucas impossibility theorem in crisis management. However, this impossibility theorem is not valid both in theory and practice. There are reliable methods to identify and prevent asset bubbles in our theory of the viable market (Chen 2008, 2009a). For example, sudden changes of trading volumes in Wall Street signal speculative activities by big investors and herd behavior of noise traders. The regulating agency could easily take counter cyclic measures, such as increasing the capital reserve requirement, restricting leverage ceiling, increasing the transaction tax rate. Breaking market monopoly is the most effective way to prevent market manipulation.

As Alfred Marshall said, economics should be closer to biology than mechanics (1920). Business cycles behave more like a freeway driver than a drunken man. From historical experiences, a protracted long period of expansion is an engine to feed bubbles, even if the inflation rate is low during the economic expansion before bursting bubble like the situation before the Great Depression and the current crisis. Central bankers cannot forecast both the recession length and the turning point under the uncertainty principle in time and frequency, which imposes a lower limit in time resolution and frequency resolution. In other words, if you try to make an accurate forecast of business-cycle turning point as Lucas wished, you will lose the larger picture of how long the recession would last. Based on our observation of viable market, government policy is capable of managing the normal range of business cycles within four to five years if we shift policy goal from inflation level targeting to business cycle monitoring. Just like the heart beats in animals, too fast or too slow rhythms signal potential troubles in the biological organism. Maintaining a normal life rhythm can improve the immune system against external shocks. Therefore, structural adjustments with a policy mix of monetary and fiscal policy should be design and experiment under historical constraints and uncertain environment during the crisis. We may test the new perspective of macroeconomic policy in future events.

The only symbolic compromise Lucas did make is his last sentence, which barely mentioned the name of Keynes along with Friedman and Schwartz, but not Hayek and Minsky. For a serious reader of *The Economist* magazine, the only lesson of the Lucas defense of the dismal science is that economic theory should connect with economic reality. The fundamental lesson from this Grand Crisis is that the rational individual with unlimited want is not compatible with ecological constraints (such as global warming) and social solidarity. The human being is a social animal seeking security, happiness, and companionship. Division of labor is driven by a disciplined hand (both for individual and government) in the modern economy. Classical economics is a beginning not the end of understanding the evolving economy. Complexity science developed in physics and biology is a complementary tool with philosophy, history, and psychology in studying economic behavior and organization. There is plenty of new thinking in economics and social sciences developed in the last three decades. Hopefully, mainstream economists would open their minds and experiment with fresh ideas after this crisis.

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Enjoy your journey in a complex but colorful world!

(The comments on Lucas' defense were written on September 8, 2009 in Austin, Texas. Final modification of the Epilogue was completed on December 9, 2009 in Beijing, China.)

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.

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