Emerging Technology as Positive Uncertainty Driving Economic Change

- **Ping Chen**
- **China Center for Economic Research, Peking University**
- pchen@ccer.pku.edu.cn
- http://pchen.ccer.edu.cn/

And

- **Prigogine Center for Studies in Statistical Mechanics and Complex Systems, University of Texas at Austin**
- pchen@physics.utexas.edu

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From **Ilya Prigogine**:
Order Out of Chaos (1984)

- Where **classical science** used to emphasize **permanence**, we now find **change** and **evolution**.
- Our **vision of nature** is undergoing a radical change toward the **multiple**, the **temporal**, and the **complex**.

Classical World of Certainty: No Space for Emerging Technology

- Arrow-Debreu model (micro): all commodities have infinite lives
- **No product cycles, no technology wavelets** exist

- Real business cycle school (macro):
- Technology innovations act as **random noise**, no impact on structural change

- Efficient market in finance theory: **information shocks** as **Brownian motion** driving stock fluctuations

What Is the **Driving Force** of **Economic Growth** and **Business Cycles**?

- **Equilibrium school**: **external shocks** or random innovations (**Frisch**)
- **Evolutionary school**: **entrepreneurship** and **technology revolution** (Schumpeter)
- Can we test which approach is better in understanding economic movements? YES

Discovery of Economic Complexity

- Empirical and theoretical evidence of **monetary strange attractor** (Chen 1985-87)
- Wide evidence of **color chaos (persistent cycles)** from **stock market index** and **macro indexes** (Chen 1994-1996)

- Implications of finding economic chaos:
- **Non-integrable** economic system > limitation to ***regression analysis*** in ***econometrics***
- Endogenous mechanism of nonlinear dynamics > challenge to ***Brownian motion model*** in **macro & finance**

Re-examine Empirical & Theoretical Foundation of Equilibrium Economics

- **Econometrics**: **Frisch model** of ***noise-driven harmonic cycles*** (1933) > a perpetual motion machine, it **could not generate persistent cycles**

- **Macro**: **Lucas model** of ***microfoundations*** and ***rational expectations*** > against the **Principle of Large Numbers**

- **Finance**: **Brownian motion model** of stock prices > ***explosive nature*** of diffusion process

Evolutionary Dynamics: A Better Alternative

- **Three levels** of economy: **micro-meso-macro**
- Micro: **Lotka-Volterra model** of **emerging technologies** and **learning competition**
- Macro: **birth-death process** and **nonlinear oscillation**

Frisch Model Failed to Generate ***Persistent Business Cycles*** (Chen 1999)

- The observed auto-correlation will be **damped exponentially** (Wang and G. E. Unlenbeck 1945);

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

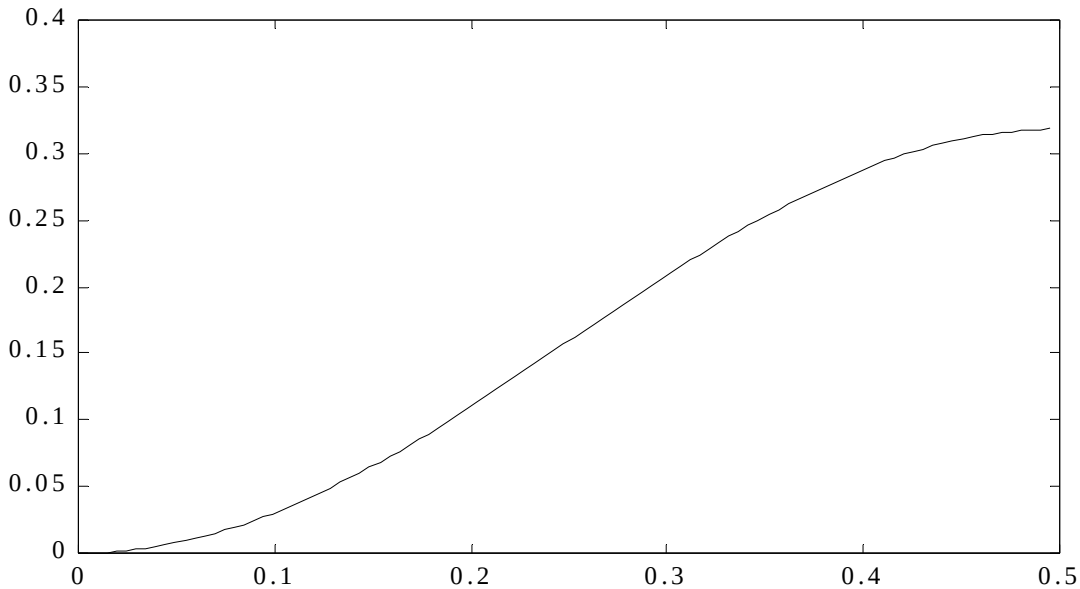
- For the Frisch model of the U.S.business cycles, **American business cycles** would be ceased within **4~10 years!**

Myth about the Frisch Model

- **Frisch was not the FIRST**: G.E.Uhlenbeck and L.S. Ornstein, "On the Theory of Brownian Motion," *Physical Review*, 36(3), 823-841 (**1930**).
- **Frisch's Informal conference paper**: R. Frisch, "Propagation Problems and Impulse Problems in Dynamic Economics", in *Economic Essays in Honour of Gustav Cassel*, George Allen & Unwin, London (**1933**).
- 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**) but **never appeared** in *Econometrica* since 1934.
- Frisch **never mentioned a word** about his prize-winning model in his **Nobel speech in 1969** (Frisch 1981).

Equilibrium Illusion of ***Efficient Market***: observation through a **Whitening Looking Glass** (**FD**)

$$X(t) = FD[S(t)] = S(t+1) - S(t)$$

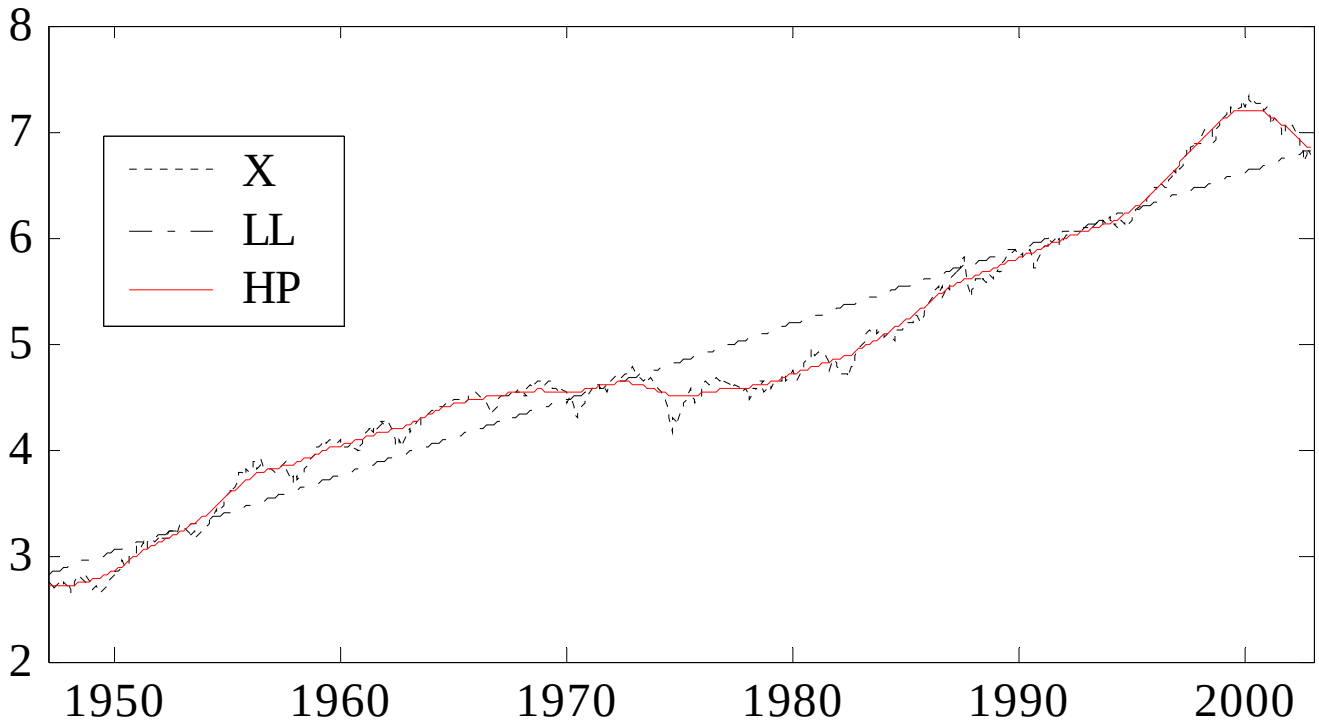


- **Frequency response** for the FD filter

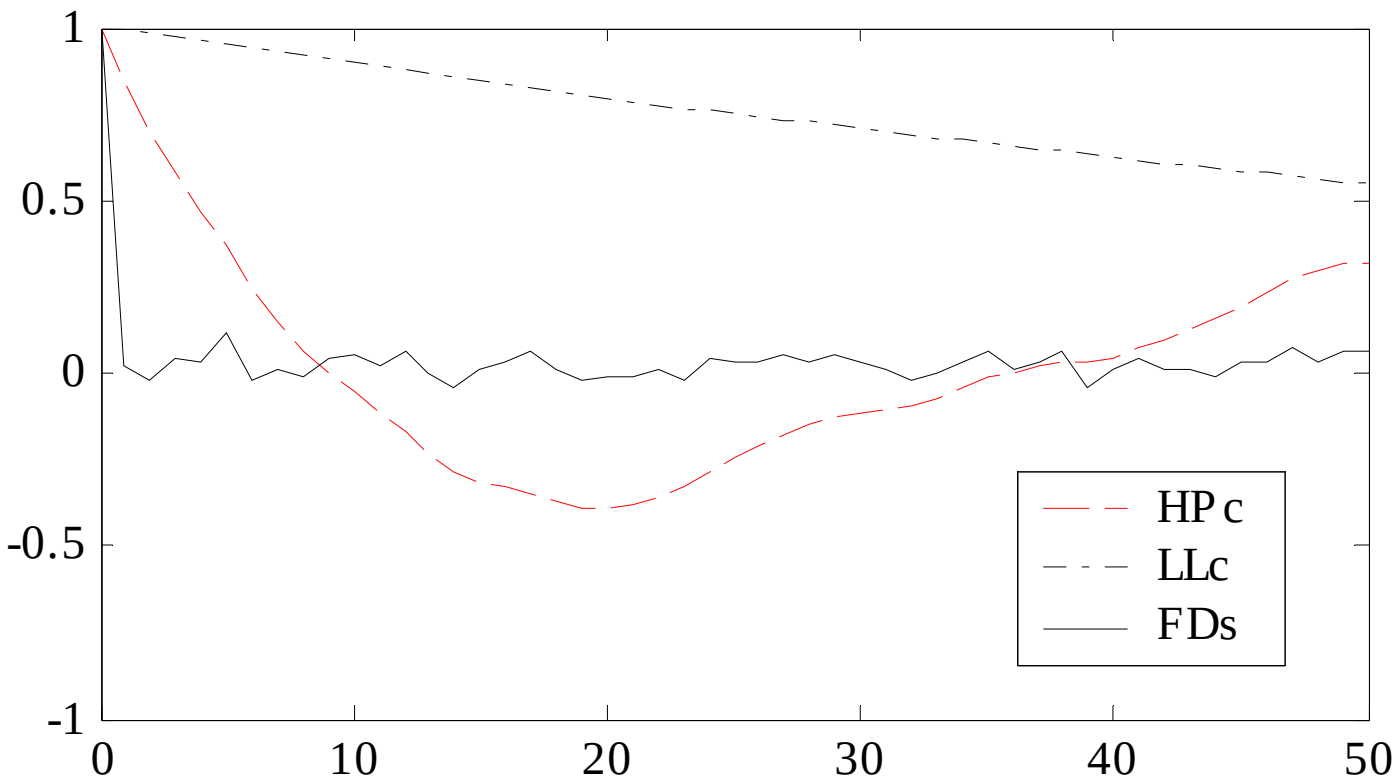
S&P500 Stock Price Index

with log-linear (**LL**) and **HP** growth trends

(**VHP** filter for **von Neumann-Hodrick-Prescott**)



Different Images of **Auto-Correlations**



Separating **Noise** with Cycles in Gabor Space

- **Non-stationary time series analysis**: An of Fourier analysis

- **Gaussian wavelets** in ***Gabor time-frequency space*** > projection with **minimum uncertainty**

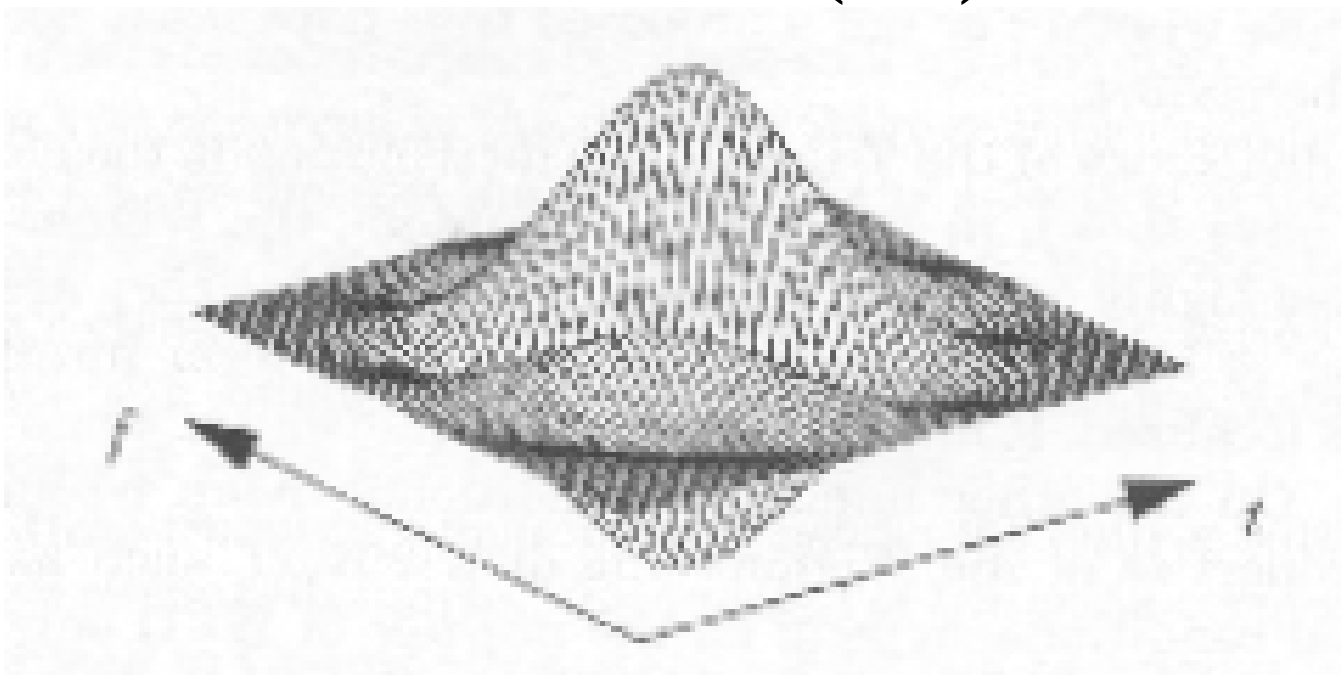
- **Time-dependent filter**

The Coherent State (Gaussian Packet, Gabor Wavelet)

$$WD_b(t, \omega) = 2 \exp\{- [(t/\sigma)^2 + (\omega\sigma)^2] \}$$

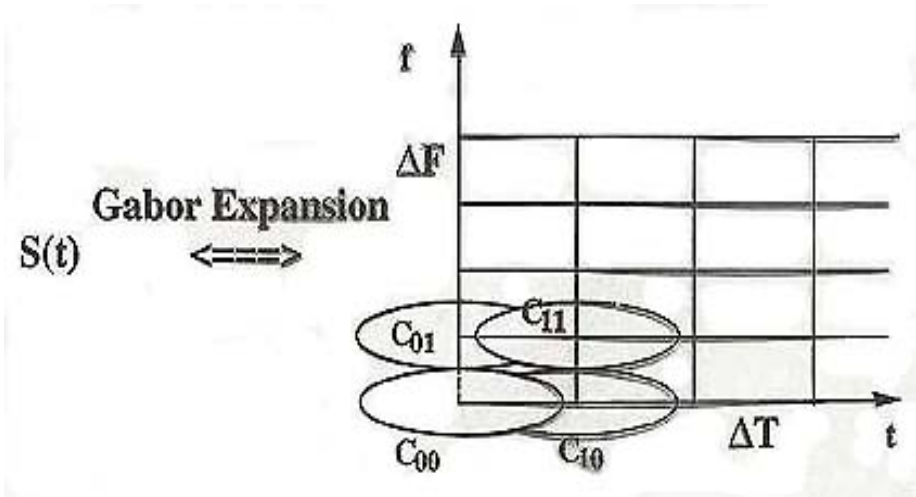
The Uncertainty Principle in Quantum Mechanics & Information Theory

$$\Delta t \, \Delta f \geq (1/4\pi)$$

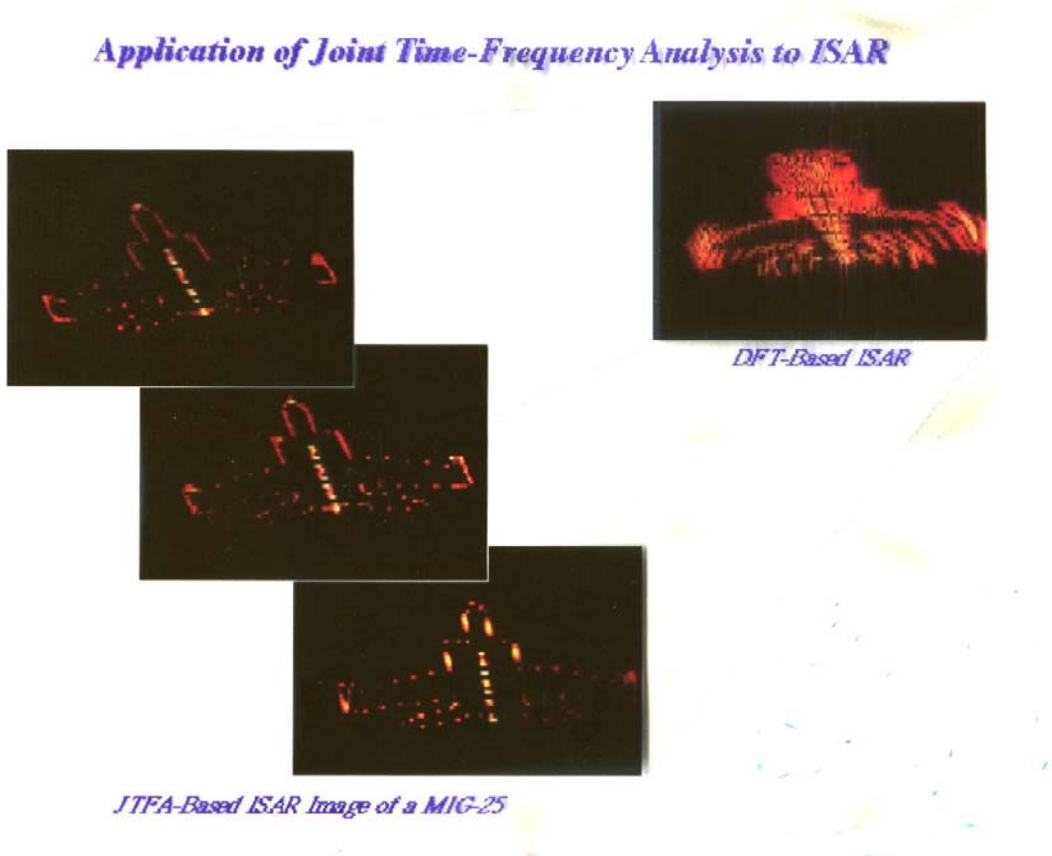


Gabor Space (1946) in discrete time-frequency space

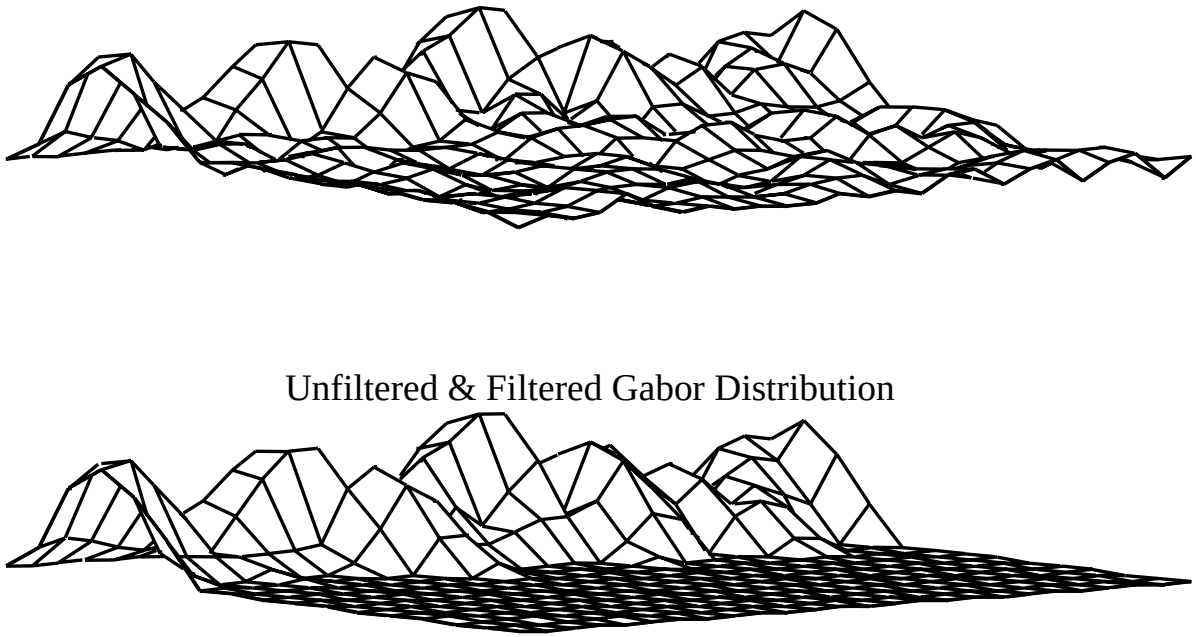
- Minimum uncertainty in time-frequency space
- Non-orthogonal base function



Stationary (*Fourier Transform*) vs. Non-Stationary (*WGQ*) Time-Frequency Analysis

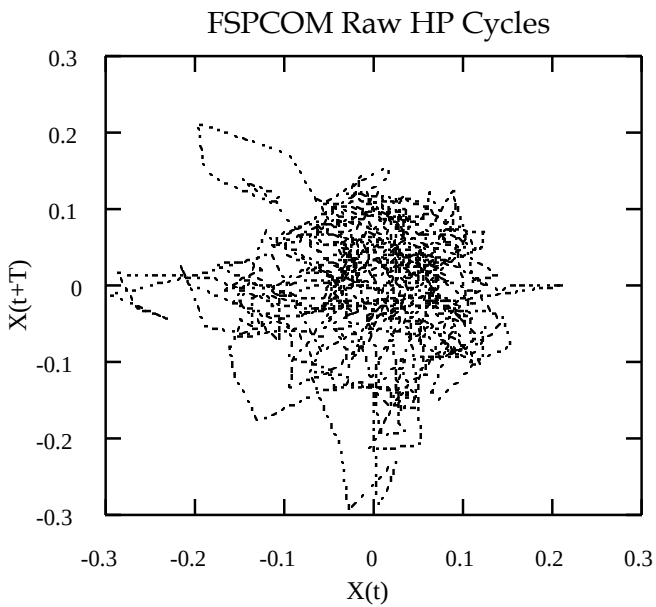


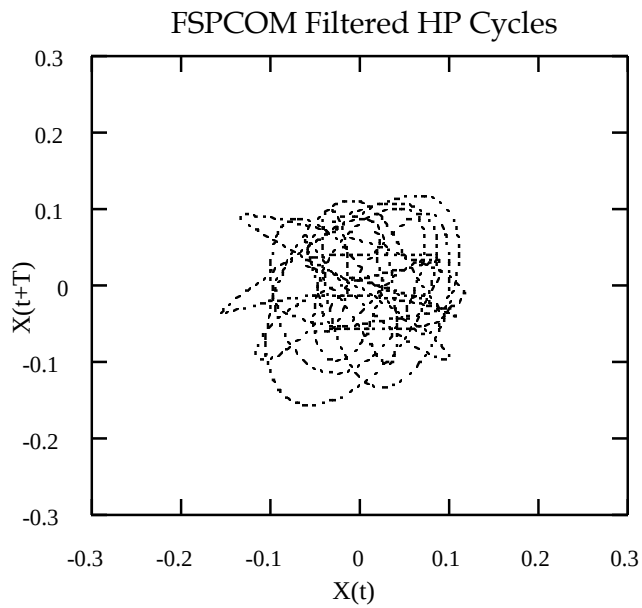
Separating signals and noise in Gabor (time-frequency) space



Unfiltered & Filtered Gabor Distribution

Evidence of Strange Attractor in Stock Market by WGQ (Wigner-Gabor-Qian) Representation

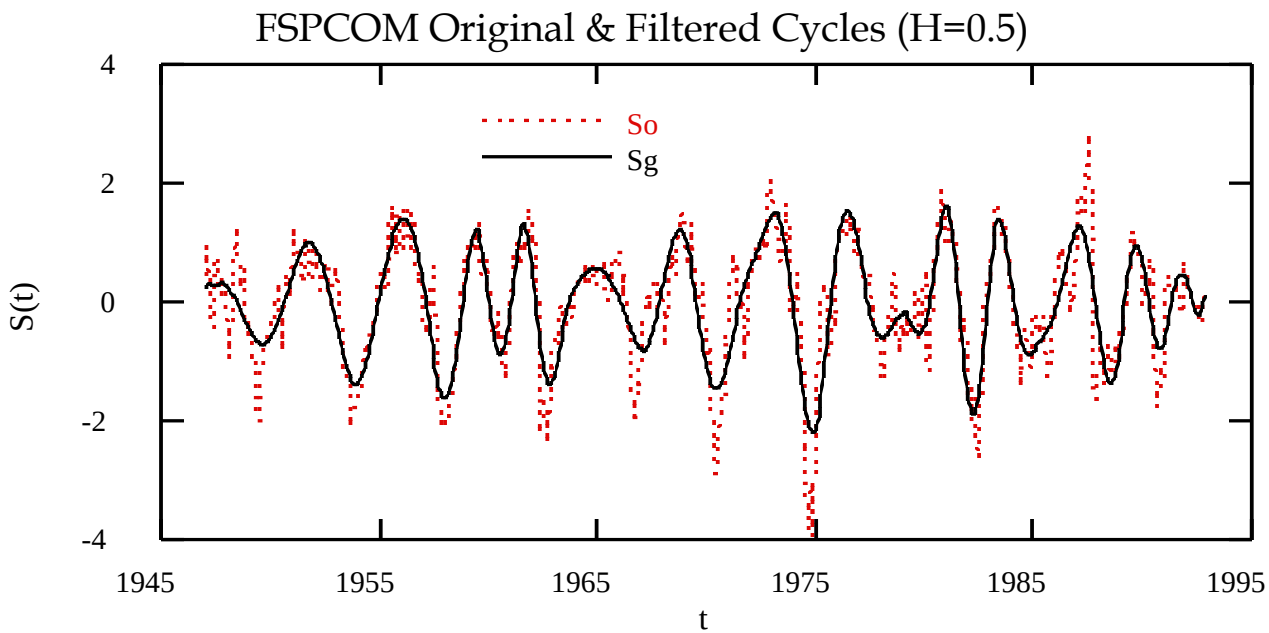




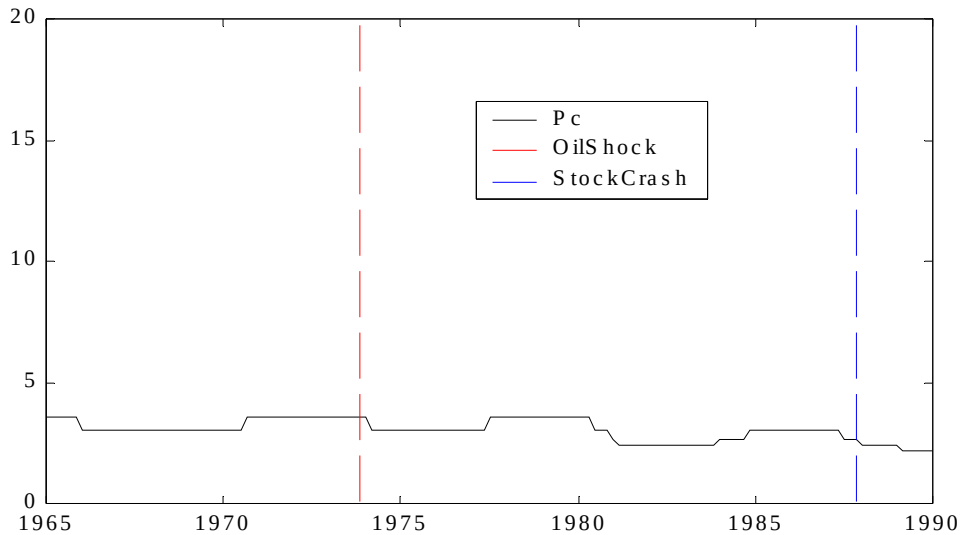
Stock Price Indexes (Standard & Poor 500)

Correlation dimension = 2.5

Variance of color chaos = 69 %



Natural Experiments and **Economic Diagnosis**: ***External Shocks*** (Oil Price Shock in 1973) vs. ***Internal Instability*** (Stock Market Crash in 1987)



External shock: frequency moved AFTER the shock
Internal instability: frequency moved BEFORE the shock

Failure of **Friedman Spirits** (~ ***Maxwell Demon***) for **Efficient Market**

- **Arbitrage risk** (De Long et al 1990)
- **Information cost** (Grossman and Stiglitz 1980)
- **Information ambiguity** (limited data, time delays, dynamical uncertainty)
- **Limited replication** of winner's strategy under **complex dynamics**

Lucas Fantasy of **Microfoundations & Rational Expectations**

- **Voluntary unemployment** based on ***inter-temporal substitution*** between ***work*** and ***leisure***
- Source of business cycles is in **labor market**
- **Technology metabolism** plays **no role** in growth dynamics

The Principle of Large Numbers for Positive Variables

- $S_N = X_1 + X_2 + \ldots\ldots + X_N$

- **Relative Deviation** (RD) =

$$\frac{STD(S_N)}{Mean(S_N)} \approx \frac{1}{\sqrt{N}}$$

Numbers of **Households** and **Firms** in 1980 of the US Economy

- Realistic Number and Potential Relative Deviations

Micro-Agents	Households	Corporations*	Public Companies
N	80.7(million)	2.9(million)	20,000
Ψ^* (%)	0.01	0.05	0.7

*Here, we count only those corporations with more than $100,000 in assets.

The **Relative Deviation** and **Implicit Number** For **Macro Indexes** under ST and HP Methods

Ψ (%) [N*]	GDPQLn	GCQLn	GPIQLn	LBMNULn
ST	1.2 [7,000]	1.4 [6,000]	2.2 [2,000]	1.1 [8,000]
HP	0.22 [200,000]	0.16 [400,000]	1.3 [6,000]	0.43[50,000]

- **GDPQ –** US **Real GDP** quarterly
- **GCQ –** US **Real Consumption** quarterly
- **GPIQ –** US **Real Investment** quarterly
- **LBMNU –** US Non-Farm **Business Hours** quarterly

Weak microfoundations in **labor** and **producer market**

The observed implied numbers predicted by the Lucas model is 400~ 500 times smaller (RD is 20 times larger) than in US real economy.

Possible microfoundations

in **financial markets** and **industrial organization**

not in **labor** or **producer market**

Implication >

Three layer structure (**micro**, **meso**, **macro**)

rather than **two layer structure** (**micro**, **macro**)

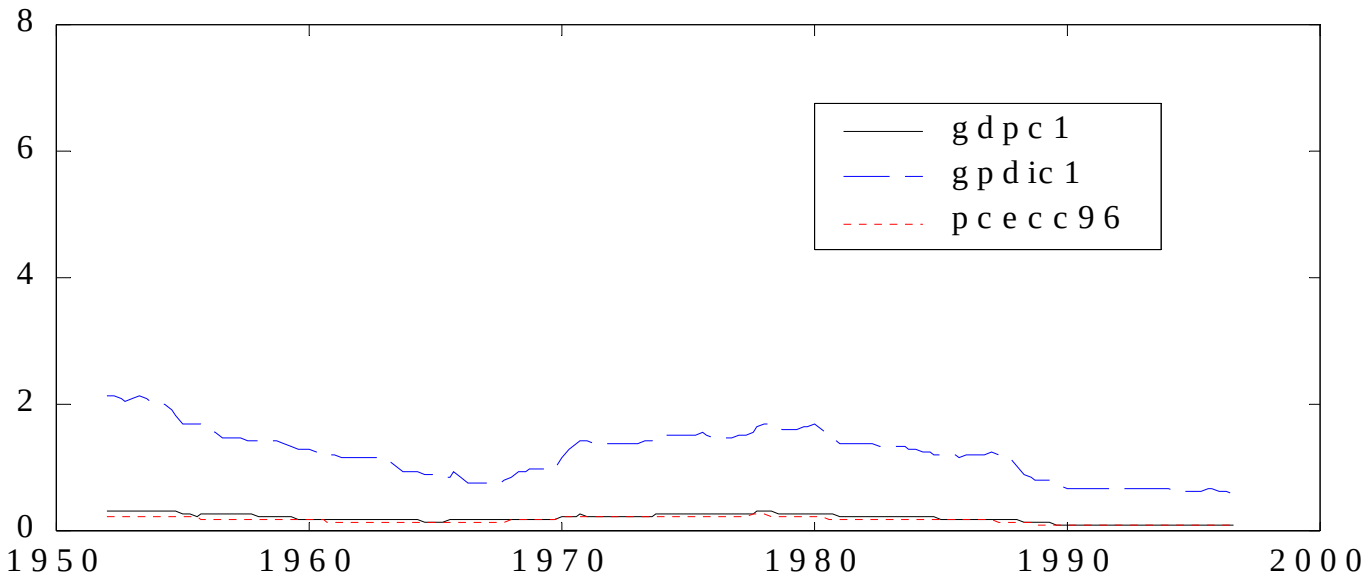
in economies

Failure of the Lucas Model of Rational Expectations and Inter-temporal Substitutions

- Relative prices move in opposite directions: Rising demand of leisure will raise leisure prices, which would induce arbitrage activities

- Arbitrage activities by rational agents would cancel out inter-temporal substitution.

Stable RD in US **Macro Indexes: Strong Evidence** of **Resilient Live Market**



RD Behavior for **Stochastic Models**

Order	Brownian motion	**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	$\sim e^{\frac{\sigma^2}{2}t}\sqrt{(1-e^{-t\sigma^2})}$	$\sim \frac{1}{\sqrt{N_0}}$	$\frac{1}{\sqrt{t}}$

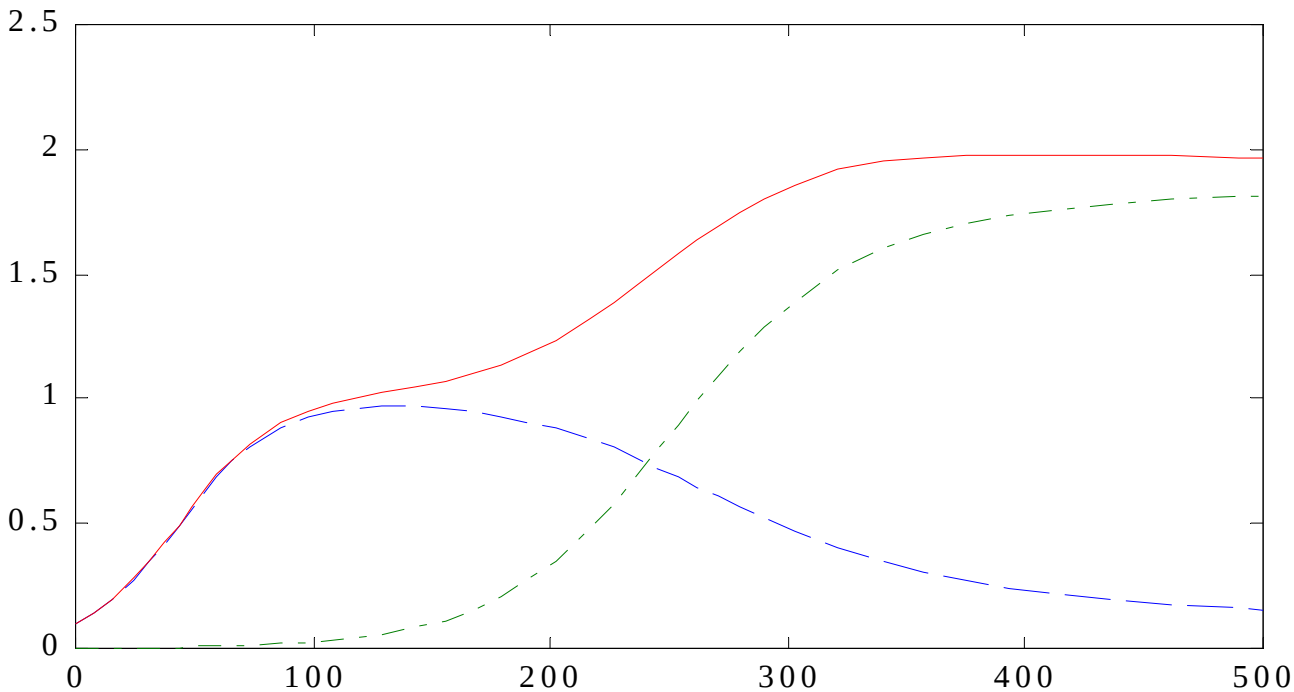
- **Random walk** is **damping** over time
- **Brownian motion** is **exploding** over time
- Only the **Birth-death process** is **stable** in time**,** which is a **statistical** model of **endogenous fluctuations**

Emerging Technologies and **Positive Uncertainty**

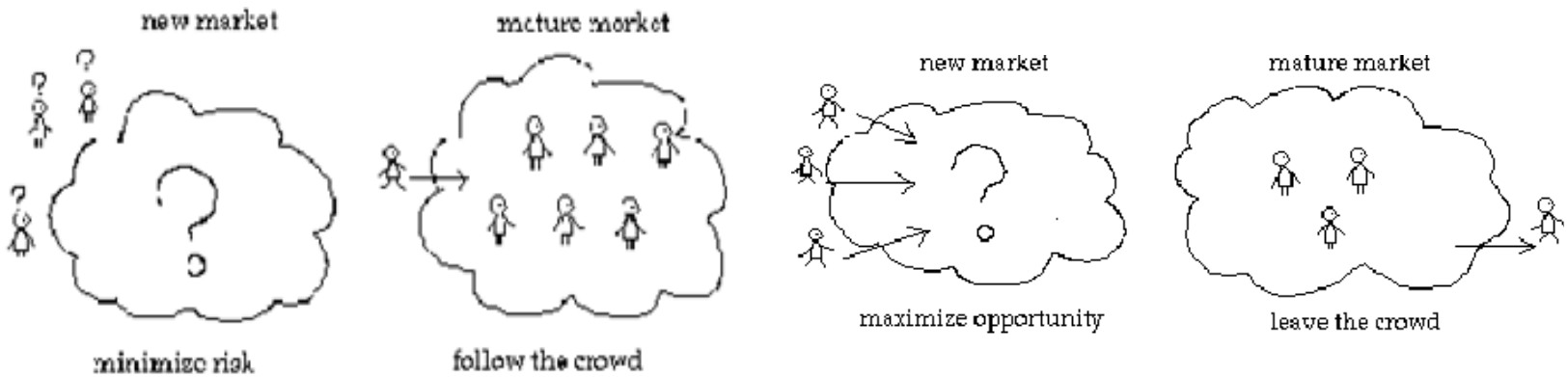
- Emerging technologies as **deterministic (logistic) trajectory** of **positive uncertainty**

- **Macro**: **endogenous mechanism** of birth-death process and color chaos in economic dynamics
- **Industry**: **rise and fall** of **technology wavelets** and **product cycles**

Source of **Growth Cycles** and **Over Investment**



Corporate Strategy in **Learning by Trying**: **Risk Aversion** vs. **Risk Taking** Behavior



Schumpeter's Entrepreneurship and **Creative Destruction**

- **Later-comer's advantage** in **catching-up game**: Japan and Microsoft
- **First-mover's strategy** in **survival game**: **learning faster or die**

- Division of labor is **limited by** ***market extent*** (Adam Smith)
- **Trade-off** between ***stability*** **and** ***complexity*** (Chen 1987)

Comparative Lessons in Corporation Strategy

- **Equilibrium school**: **price is always right**
- No role for technology innovation & entrepreneurship creativity

- **Evolutionary school**: **price** is always **over-reacted** under social interaction
- **Vision** and **leadership** in **technology** and **industry** is a driving force in economic growth

Policy Implications facing **Positive Uncertainty**

- **Source of innovation & crises: Meso economy** in **three layers** of **economic organism** (Schumpeter, Keynes, Minsky):

  micro - financial intermediates – macro

- **Policy** change: from **demand side** to **supply side**, from managing **monetary shocks** to **technology waves** (Rostow)

Positive Attitude with *Business Cycles* and *Structural Change*

- **Equilibrium school**: business cycles are bad, policy aimed to eliminate cycles;
- **Equilibrium order** is characterized by ***steady state*** plus ***random noise***

- **Evolutionary school**: ***product cycles*** and ***business cycles*** are essential for economic metabolism and technology advancement
- **Economic order & complexity** is characterized by ***living rhythms***,and ***birth-death process***

Limitation of **Economic Simplicity**

- Failure of **representative agent model** and **methodological individualism** in macro > Role of **social interaction**
- Failure of **homogeneous model** of microfoundations > Importance of **structural analysis**
- Failure of **linear** (**regression**) **thinking** in econometrics > **Nonlinear trend** + **complex cycles**

Potential Danger of **Disorder Image**

- **Over-tune** on **negative implications** in ***chaos*** and ***uncertainty*** within complexity camp:

- The term of "***chaos***" and its better alternatives: ***nonlinear oscillator***, ***complex cycles***, ***biological clock*** > **higher kind of order** than **steady state** or **random noise**
- ***Butterfly effect*** > ***limited predictability*** vs. ***total unpredictability***
- ***Edge of chaos*** > ***band of coherent structure*** & ***resilient regime***

Complexity Science & Economic Thinking

- Starting from **empirical pattern** rather than **theoretical doctrine**: convergence/diversity, diffusion/concentration, noise/waves
- **Classification** of **observed dynamical system**: diffusion/reaction, optimization/evolution, linear/nonlinear, deterministic/stochastic, time scale (short/medium/long)
- **Identify** main **mechanism**, main **structure**, and main **variables(indicators)**
- **Simplify math representation** by **proper base function/building block**

Conclusion

From **Efficient (Static) Market**

with little room for **innovation** & **creativity**

*To **Resilient (Live) Market***

with wide space for **strategic thinking** & better understanding of **coherent market**

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