# Alternative Policies after the Financial Crisis:

# New Thinking from Complex Evolutionary Economics

**Ping Chen**

Center for New Political Economy, Fudan University, Shanghai, China

National School for Development, Peking University, Beijing, China

Email: pchen@nsd.pku.edu.cn

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## Abstract

The 2008 financial crisis shocked the equilibrium paradigm of neoclassical economics. According to the efficient market hypothesis and rational expectation theory, there is little possibility for a market crisis under the "invisible hand" of a self-stabilizing market. The disequilibrium school emphasizes the destabilizing effect of herd behavior, but falls short in policy recommendations if markets are governed by fat tail, fractal, unit root, power law, or Black Swan models. The study of economic complexity greatly extends our scope to nonlinear and non-equilibrium mechanism in economic dynamics.

In this article, we will first study the origin and nature of the crisis that reveals the fundamental flaws in neoclassical economics and requires a paradigm change in economic thinking. Then, we will discuss alternative policies in complex evolutionary economics, which is capable of understanding the changing world after the crisis.

## I. Introduction

The 2008 financial crisis shocked the very foundation of neoclassical economics, since equilibrium models in neoclassical economics simply deny the possibility of endogenous business cycles and financial crises. During and after the crisis, many countries adopted monetary and fiscal policies for stabilizing and stimulating economies according to the textbook economics of IS-LM model that resulted in widely different results. The critical role of structural reform is missing in the two-level framework of micro and macroeconomics.

In this article, we will discuss two main issues: First, the origin and nature of the crisis that reveals the fundamental flaws in neoclassical economics and demands a paradigm change in economic thinking; Second, alternative policies in complex evolutionary economics, which is capable of understanding the changing world after the crisis.

Methodologically speaking, the mainstream economic thoughts have a common problem: linear one-way thinking with equilibrium perspective. Mainstream economists often ignore economic complexity, including nonlinearity, non-equilibrium, non-stationary, social interactions, and the large picture of ecological-industrial systems (Dopfer 2005, Elsner 2012). We have better alternatives both in theory and practice by means of the new perspective, since we live in a nonlinear and non-equilibrium world under open competition (Chen 2010).

## II. Diagnosis of the Cause of Financial Crisis

There are three questions related to the debate on this crisis. First, was the crisis caused by an endogenous mechanism or by external shocks? Second, can we identify warning signals for coming crises? Third, do we have any instruments to deal with financial crises? There are two competing approaches in addressing these questions.

### (2.1) Static statistics and equilibrium models have little understanding of market instability and financial crisis

The static methods of statistics in econometric analysis have no clear answers to the above questions. According to the efficient market hypothesis and rational expectation theory, there is little chance for market crises under the "invisible hand" paradigm if market fluctuations follow a random walk or Brownian motion. The Frisch model of noise-driven cycles was a perpetual motion machine that cannot maintain persistent business cycles (Frisch 1933, Chen 2010, chapter 12). The popular dynamic stochastic general equilibrium models are variations of the noise-driving model, including rational expectations, RBC models, and financial accelerators (Lucas 1981, Kydland and Prescott 1982, Bernanke et al 1996). The equilibrium theory simply rules out the possibility of endogenous instability because their market model is self-stabilizing under the equilibrium-optimization paradigm and attribute business fluctuations only to external shocks.

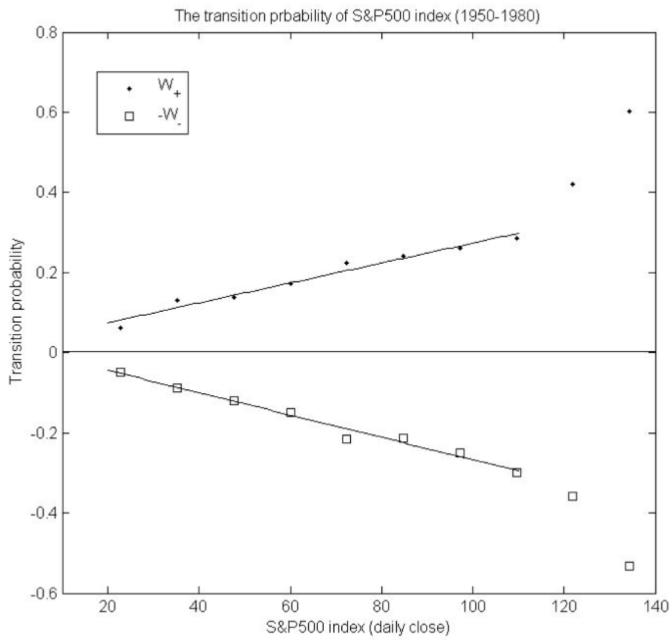
We found out that noise component only accounts for 30% of market variance. We have solid evidence that financial market indexes are non-stationary and its main component can be explained by nonlinear color chaos (Chen 1996). Business cycles are mainly generated by nonlinear endogenous mechanisms. Schumpeter's idea of the biological clock can be described by “color chaos” (Chen 1988, 2005).

We should point out that the disequilibrium models do provide explanations for large business fluctuations, such as fractal Brownian motion and power law models in econophysics (Mandelbrot 1997, Mantegna and Stanley 2000). However, a static disequilibrium model has little power in analyzing non-stationary time series and historical events. We had little means to stabilize the market if market fluctuations were governed by fat tail, fractal Brownian motion, unit root, power law, or Black Swan mechanisms in disequilibrium theory (Chen 2015).

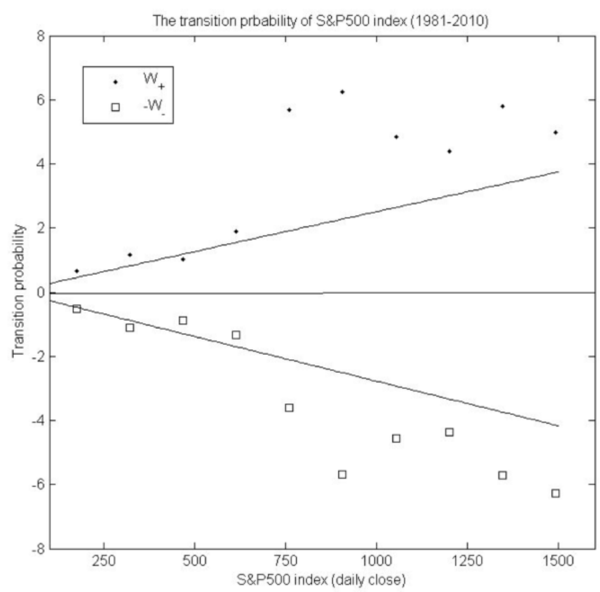
**(2.2) Time-dependent transition probability and Regime Switching in Financial Markets**

The 2008 financial crisis started with the collapse of the derivative market in the U.S. We discovered before the crisis that the Black-Scholes model in option pricing is explosive in nature (Chen 2005, 2010). The base model in finance theory is Brownian motion that is a representative agent model without herd behavior. The better alternative model is the population model of the birth-death process, which is capable of understanding both calm (quasi-linear regime) and turbulent (severe-nonlinear regime) markets including breaking point or market crises.

We developed the stochastic dynamics of changing high moments and regime switch, which can be fully described by a nonlinear birth-death process. Its time-dependent transition probability can be estimated from empirical data. We can directly observe the transition probability from the empirical time series by means of the birth-death processes for price dynamics (Tang and Chen 2015). We found two different market regimes in the recent history of the US financial market that can be seen from Fig.1.




(1a)




**(1b)**

**Fig.1.** The transition probabilities ($W_+$ and $-W_-$) of the S&P 500 daily close.

The horizontal axis is the price level of the S&P 500 daily index. The upper curve $W_+$ describes the transition probability of the price moving up that signals the strength of the bull camp, while the lower curve $W_-$ describes the transition probability of the price moving down that signals the strength of the bear camp. Market movements were driven by the net effect between the bull and bear camp.

(1a) The transition probability curve in 1950-1980. Its shape is near linear, which is the typical feature of a calm market.

(1b) The transition probability curve in 1981-2010. Its shape is highly nonlinear with two visible humps or dips, which is the typical feature of a turbulent market. The two straight lines here are the extensions of the straight fitting lines in (1a).

Clearly, the turbulent regime occurred in the period of liberalization policy. We can estimate when the market broke down by means of the master equation of the birth-death process.

The market tide driven by collective psychology can be visualized as a curve. Its falling segment represents a market tide towards equilibrium while a rising segment signals a market tide towards disequilibrium. Fig. 2 shows the numerical results of the net daily change rate, which indicates down – up – down market tides. The up phase describes a collective fad for a market bubble. We assume that the turning point from the up to the down phase may generate a market breakdown or crisis, and therefore a critical point of financial crises. The critical behaviors of crises have also been characterized by diverging high moments and extraordinarily large trading volumes.

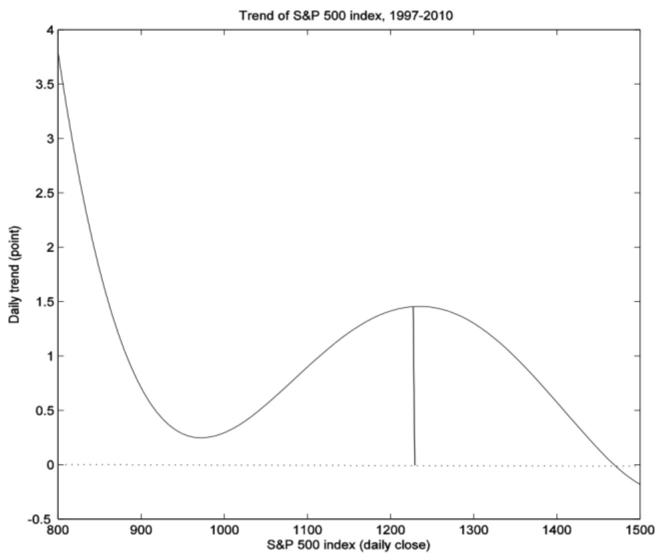



FIG 2. The curve of a changing market tide in terms of the net daily change rate (1997-2010). The curve is calculated from the $4_{th}$ degree polynomial fitted transition probability from 1997-2010. The up segment indicates two hot-speculation periods from 950 to 1229 in 1997-2000 and 2003-2008, and panic in 2008. The vertical line marks the turning (critical) point in market psychology, which is 1229 in the price level.

From Fig. 2, the turning point can be estimated from the numerical solution of the nonlinear birth-death process. We have quantitative evidence to infer that the stock market breakdown may happen near the 1229-th point. According to historical data, the S&P 500 index closed at 1209.13 on 25-Sep-2008, when the Office of Thrift Supervision (OTS) seized Washington Mutual, and sold its banking assets to JP Morgan Chase for $1.9 billion. This event was the peak of a chain of events preceding the 2008 financial crisis. Before this event, Fannie Mae and Freddie Mac were nationalized by the U.S. government, Lehman Brothers bankrupted, AIG experienced a liquidity crisis. Then, the stock market went to panic since 26-Sep-2008. Effectively, our estimation of the historical turning point provides an accurate indicator for coming crisis in addition to the high moments approach in crisis warning.

Financial deregulation is based on the argument of reducing transaction costs (Coase 1979). This argument is dubious since deregulation may have increased herd behavior and market volatility. From a complexity perspective, selection is more relevant for a vital economy with multiple regimes (Chen 2007).

### (2.3) High moment representation and crisis warning signal

Both transition probability estimation and regression analysis can only be conducted ex post. However, we do have a new tool for monitoring market instability in practice. The rising tide signals an upcoming bubble in the financial market. This is a valuable indicator for an early warning of a crisis.

Neoclassical finance theory only considers the first (mean) and second moment (variance) in analyzing financial risk. We find that the high moment representation provides more critical information for diagnosing dynamical instability (Tang and Chen 2014). High (3rd to 5th) moments would rapidly rise one-quarter before and during the crisis. These phenomena indicate a turbulent market, which can be understood by herd behavior induced by interacting agents. High moments are insignificant in a calm market (Fig.3).

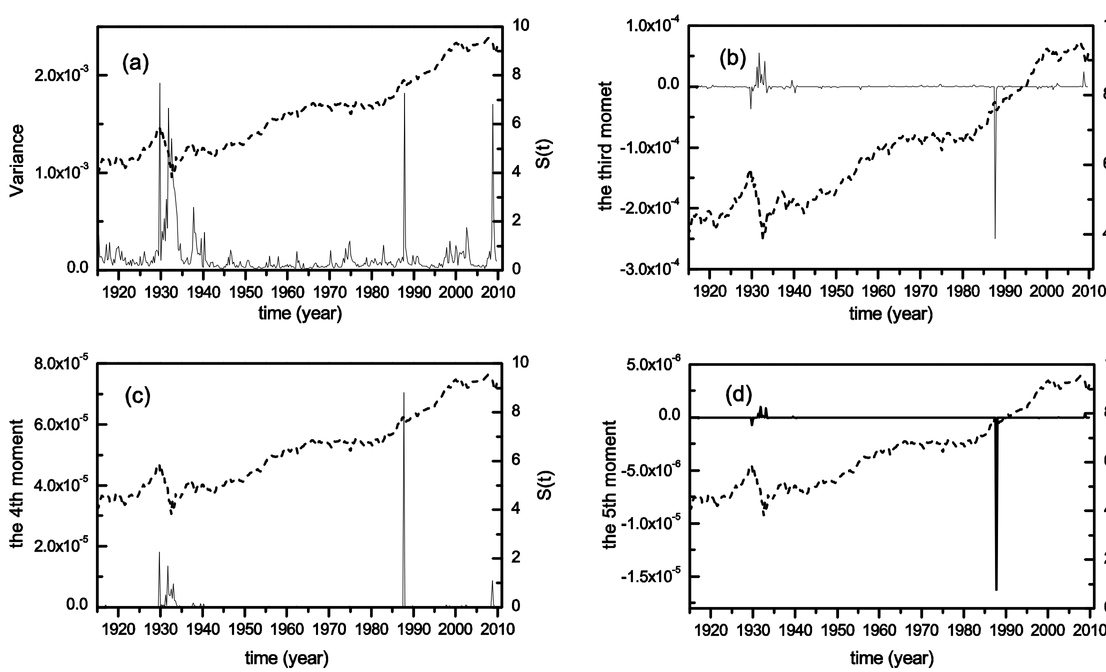


FIG. 3. The quarterly moments (solid lines) of the Dow-Jones Industrial Average (DJI) index. The original S(t) (dashed lines) is the natural logarithmic daily close price series. Each point in the solid line is calculated with a moving time window; its width is one quarter. Plots (a), (b), (c) and (d) correspond to 2nd, 3rd, 4th and 5th moment, respectively. The magnitudes of each moment representation are $10^{-5}$ for variance, $10^{-8}$ for 3rd moment, $10^{-9}$ for 4th moment, and $10^{-11}$ for 5th moment. The daily data were from 2-Jan-1900 to 1-Sep-2010 with 27724 data points. Here we choose $\sigma_0^2 \sim 10^{-5}$ as the normal level. We would consider high moments when they reach the level of $10^{-1}\sigma_0^2$ or higher.

Changing high moments (in a range of 100 – 1000 times of normal variance) in financial history show that the real market does not follow a stable distribution. Therefore, the static picture of the distribution’s tails may distort the non-stationary nature of market instability and crisis. The dramatic rising of high moments provides a better signal of market instability than traditional measures, such as the price level changes or fat tails in a static distribution.

Based on the above discussion, we may conclude that the financial crisis was induced by liberalization policy during the last three decades. The turbulent market is characterized by a nonlinear regime in transition probability and a coming crisis is signaled by dramatically rising high moments. The mass psychology of heard behavior can be studied by the population model of the birth-death process, which is more powerful than the representative agent model of a random walk or a Brownian motion model. Time-dependent transition probability and high moment representation provide new tools in non-stationary time series analysis, which are useful in crisis diagnosis and monitoring the market.

## III. Policy Alternative After the Crisis

The second issue in this article is how to deal with financial crises and why country performances varied greatly after the 2008 crisis. We found that existing tools in mainstream economics is not enough in dealing with crisis. The new perspective of complex evolutionary economics provides new policies with a better understanding of the structural causes of financial crisis and the limits of neoclassical economics.

**(3.1) Limitation of the IS-LM model for monetary policy in dealing with the crisis**

One remarkable lesson in this crisis is the limitation of monetary policy during the crisis. Friedman once believed that expansion policy in monetary supply might prevent the Great Depression (Friedman and Schwartz 1963). Both the U.S. Federal Reserve and EU Central Bank carried out large scale of quantitative easing, but its effect is limited at best (Bernanke 2013).

According to the IS model in macroeconomics, lowering the interest rate should increase investment and output. This is a typical case of one-way thinking, which is operational only for the consumer's market in a closed economy without structural changes. In an open economy under global competition, a lower interest rate would lead to three different outcomes: (a) increasing investment if the economy is healthy and competitive; (b) capital flight if other markets (such as emerging markets) have better growth potential; (c) holding cash when uncertainty rules the market. Clearly, the neoclassical model of the IS curve is an over-simplified model for a complex economy. The new global world must understand the multiple possibilities with open competition and regime switch.

There is an old debate between the endogenous and the exogenous school in money supply (Wicksell 1898). The discovery of monetary chaos offered strong evidence for endogenous money (Chen 1988), since exogenous model is based on random walk or Brownian motion mechanisms (Chen 1996). The limited effect of the monetary policy during this crisis provided further historical experience that monetary policy is constrained by economic conditions.

### (3.2) Meso Foundation and Competition Policy

Economic virtualization and the rise of the monetary economy put financial oligarchs in the driving seat in globalization that creates economic polarization and welfare crises in both developed and developing countries (Johnson 2009). The meso-foundation theory of business cycles reveals the importance of competition policy and anti-trust policy in an international financial order (Chen 2009).

The counter-Keynesian revolution led by Lucas played a key role in market liberalization in the last three decades. Lucas made a strong claim that business cycles could be explained by an equilibrium (rational expectations) mechanism of workers' choices between work and leisure (Lucas 1981). His micro-foundations theory is widely discredited by the 2008 crisis. His theoretical flaw was revealed by empirical observations based on the principle of large numbers (Chen 2002). According to Schrödinger (1944), the founder of quantum mechanics and quantum biology, there is a salient relationship between the number of micro-elements and the variability of aggregate fluctuations.

$$\text{Market variability (MV)} = \frac{STD(S_N)}{Mean(S_N)} \approx \frac{1}{\sqrt{N}} \qquad (1)$$

The implication of Eq.1 is simple. The more micro-elements are involved, the less the aggregate fluctuation will be, because independent fluctuations would cancel out each other. This is the principle of large numbers. This relation can be extended from static aggregation to dynamic growth, such as the population dynamics of the birth–death process (Chen 2002).

Empirically, we can measure MV from aggregate indexes, we can also infer the effective cluster number $N_c$, at the micro-level. The empirical results are shown in Table 1.

**Table 1** Market variability and effective cluster number for various aggregate indexes

| Item | MV (%) | Nc |
|---|---|---|
| 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 |

Notes: For non-stationary 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 five years (Chen 2002). Data 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.

From Table 1, we immediately find out that there is no evidence for rational expectations and representative agent models in macro dynamics, since the observed cluster numbers are much larger than one.

The number of households, corporations and public companies and their implied orders of MV in 1980 are given in Table 2.

Table 2 Numbers of households and firms in the United States (1980)

| *Micro-agents* | Households | Corporations* | Public companies |
|---|---|---|---|
| *N* | 80 700 000 | 2 900 000 | 20 000 |
| *MV (%)* | 0.01 | 0.1 | 0.7 |

* Here, we count only those corporations with more than $100 000 in assets. The data source is the U.S. Bureau of Census.

From Tables 1 and 2, we can see that household fluctuations contribute only about 5 % of fluctuations in real gross domestic product (GDP) and less than 1 % in real investment; and small firms can contribute 50 % of the fluctuations in real GDP or 8 % in real investment, while public companies can generate about 60 % of aggregate fluctuations in real investment. Clearly, there are very weak ‘micro-foundations’ from households or firms but strong evidence of a ‘meso-foundation’ of financial companies in macroeconomic fluctuations.

One big issue in this financial crisis is how to deal with financial oligarchs that created this crisis (Johnson 2009). The U.S. government spent huge money to save these financial oligarchs on the ground that “too big to fail”, since their failure may trigger a chain reaction in financial industry. From our perspective, these financial giants are “too complex to exist” because they amplify macro fluctuation. This fallacy of composition 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 naked 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 76 percent from $130 to $30 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.

Clearly, competition policy at the microeconomic level and in financial markets is essential to achieve macro stability. For stabilizing international financial markets, breaking-up financial oligarchs is more effective than financial regulation. Our research strongly supports the international anti-trust law for preventing the next global crisis.

From the above discussion, we can see that the traditional two-level framework of micro-macro economy is not capable of understanding the mechanism of endogenous business cycles. Our analysis based on the Principle of Large Numbers supports the three-level framework of micro-meso-macro economy. The meso level mainly includes financial sector and industrial organization, while the micro level refers to atomic players such as households and firms. Economic structure in the macro level can be better understood by using the meso level. Its importance can be seen from the following discussion.

### (3.3) Structural Reform and Industrial Policy

During this crisis, economic performance was varied greatly among developed and emerging countries (see Table 3).

Table 3 GDP Growth Rate During the Crisis (%)

| Country | US | UK | Fra | Ger | Jap | Ice | Spa | Ita | Gre | Chi | Ind | Bra | Rus | World |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | 1.8 | 2.6 | 2.4 | 3.3 | 2.2 | 9.7 | 3.8 | 1.5 | 3.5 | 14.2 | 9.8 | 6.1 | 8.5 | 4.0 |
| 2008 | -0.3 | -0.3 | 0.2 | 1.1 | -1.0 | 1.1 | 1.1 | -1.0 | -0.4 | 9.6 | 3.9 | 5.2 | 5.2 | 1.5 |
| 2009 | -2.8 | -4.3 | -2.9 | -5.6 | -5.5 | -5.1 | -3.6 | -5.5 | -4.4 | 9.2 | 8.5 | -0.3 | -7.8 | -2.0 |
| 2010 | 2.5 | 1.9 | 2.0 | 4.1 | 4.7 | -2.9 | 0.0 | 1.7 | -5.4 | 10.4 | 10.5 | 7.5 | 4.5 | 4.1 |
| 2011 | 1.6 | 1.6 | 2.1 | 3.6 | -0.5 | 2.1 | -0.6 | 0.6 | -8.9 | 9.3 | 6.4 | 2.7 | 4.3 | 2.8 |
| 2012 | 2.3 | 0.7 | 0.3 | 0.4 | 1.5 | 1.1 | -2.1 | -2.3 | -6.6 | 7.7 | 4.7 | 1.0 | 3.4 | 2.2 |
| 2013 | 2.2 | 1.7 | 0.3 | 0.1 | 1.5 | 3.5 | -1.2 | -1.9 | -3.3 | 7.7 | 5.0 | 2.5 | 1.3 | 2.3 |
| AVE(09-13) | 1.2 | 0.3 | 0.4 | 0.5 | 0.3 | -0.3 | -1.5 | -1.5 | -5.7 | 8.9 | 7.0 | 2.7 | 1.1 | 1.9 |

Here, the above data can be classified into three groups: The first group is the major developed countries including US, UK, France, Germany, and Japan; The second is the countries in severe crisis including Iceland, Spain, Italy, and Greece; The third is the major developing countries including China, India, Brazil, and Russia; The last column is the World index. The last row is five-year average growth rate from 2009 to 2013. All data show in percentage rate. Data source is United Nations Statistics.

From Table 3, we found that developed countries suffered more than emerging countries during the 2008 financial crisis, because the financial industry has more weight in developed countries. The role of economic structure is critical for understanding wide differences in economic performance. For example, Greece and Italy have long-term structural problems in balancing the budget and Iceland and Spain experienced great pain in bursting housing bubble. Aging and debt burden greatly restricting government financial policy in Europe, Japan, and the United States. In contrast, emerging countries are performing much better than developed countries, since their investments are mainly devoted to the real rather than the virtual economy. China made investments in infrastructure, especially the high-speed train, while India's economy is driven by mass consumption. In another words, economic structure matters in economic policy performance.

However, Keynesian economics falls short in understanding the structural foundation of insufficient aggregate demand and non-voluntary unemployment. Our theory of metabolic growth pointed out that excess capacity resulted from technology competition (Chen 2014). A typical growth trajectory for an industry or technology is a S-shaped logistic curve. Its growth ceiling represents resource capacity, market extent, or ecological constraint that is the function of the underlying technology. Under open technology competition, a new technology may replace an old technology or co-exist with the existing technology. These results can be seen from Fig.4.

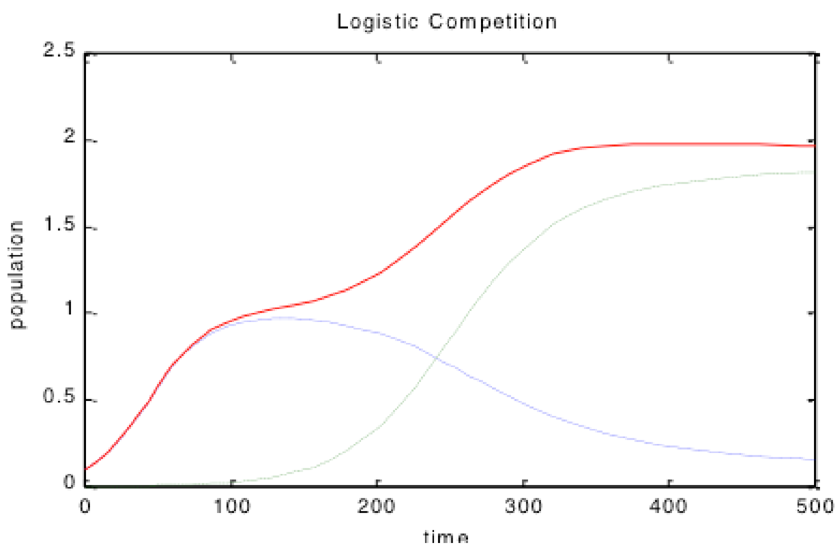



Fig. 4. Metabolic growth characterized by technology competition. The old technology (lower left line) declines when new technology (lower right line) emerges. The output envelope (upper line) is the sum of their output of all technologies. The units here are arbitrary in computational simulation. Here, $\beta$=0.4, $C_2=2*C_1$. When old and new technologies co-exist, both technologies cannot realize their full capacity. The resulted excess capacity is the roots of Schumpeter's "creative destruction".

If $C_1$ is the full capacity of technology 1, $C_2$ is the full capacity of technology 2. Technology competition will bring both aggregate growth and creative destruction. We may calculate the costs of revolutionary technology. There are two possible outcomes:

(a) When $\beta < \frac{C_2}{C_1} < \frac{1}{\beta}$ , here the competition coefficient is $0 < \beta < 1$,

Old and new technology will coexist. However, the aggregate outcome is below their full potential:

$$\frac{1}{2}(C_1 + C_2) \le (n_1^* + n_2^*) = \frac{(C_1+C_2)}{1+\beta} \le (C_1 + C_2) \quad (2)$$

Here $n_1^*$ and $n_2^*$ is realized capacity for technology 1 and 2 respectively. We can see from Fig.4 that both old and new technology have excess capacity, since neither of them could realize their full potential. This is our new understanding the origin of insufficient aggregate demand. For a numerical example, $\beta$=0.4, $C_2$=2*$C_1$, realized output is about 2.143 $C_1$ that is below the potential output of 3 $C_1$. The excess capacity is about 0.857 $C_1$.

(b) When $C_2 > C_1/\beta$, where $\beta$ is competition coefficient, $C_2$ will completely wipe out $C_1$, so that the aggregate output is equal $C_2$, while the competition cost is $C_1$. For a numerical example, when $\beta$=0.4 and $C_2$>2.5 $C_1$, $C_2$ will replace $C_1$. Even total output $C_2$ is more than 2.5 $C_1$, there is still a sunk cost of full capacity of $C_1$.

From Fig.4, we find out that technology advancement is not an equilibrium mechanism of a diffusion process, but a metabolic dynamics of creative destruction. The rise and fall of technologies can be described by technology wavelets. There is a life-cycle movement in technology competition. This picture is radically different from random walk in real business cycle theory (Kydland and Prescott 1982), since equilibrium business cycle theory ignores interruptive technology and creative destruction.

Clearly, government policy will be important during technology transition. When a new technology wipes out an old technology, the knowledge and capacity associated with the old technology becomes sunk costs. Retraining policy for unemployed workers and government assistance for industrial transition will greatly smoothen the problems during an industrial transition. When new and old technologies coexist, the government may delay or accelerate technology advancement and structural adjustment. If an interest group associated with obsolete technology is able to block the technology metabolism, laissez fair policy may delay technology advancement and lost international competition. This is true for both developed and developing countries.

### (3.4) Resource-Intensive vs. Labor-Intensive Technology

There is one visible puzzle during this crisis: How did China and India grow much faster than developed countries? We should remember that China and India have much less natural resources than developed countries, such as land on the per capita basis (Table 4).

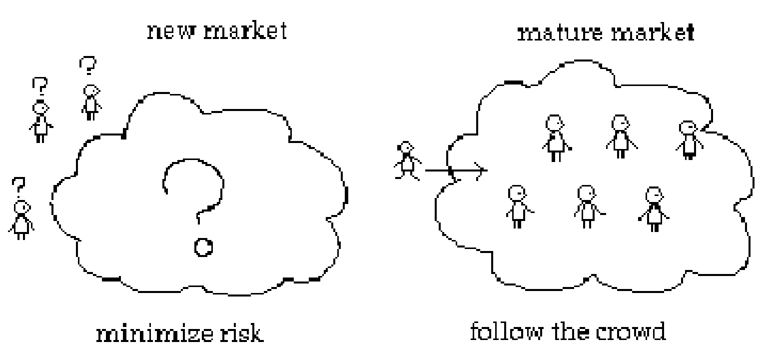
**Table 4. Cross Country Comparison in Land Resource** (Madison1998)

| Region | Arable Land (%) | Population (millions) | Arable land per capita (ha) |
|---|---|---|---|
| China | 10 | 1178 | **0.08** |
| Europe | 28 | 507 | 0.26 |
| US | 19 | 239 | 0.73 |
| fUSSR | 10 | 203 | 0.79 |
| Japan | 12 | 125 | **0.04** |
| India | 52 | 899 | 0.19 |
| Brazil | 6 | 159 | 0.31 |
| Australia | 6 | 18 | **2.62** |
| Canada | 5 | 28 | 1.58 |

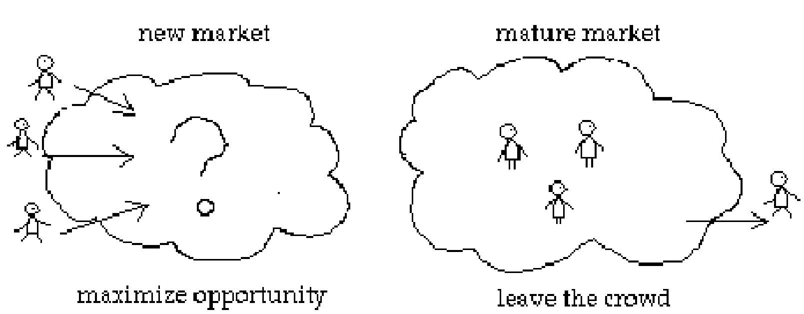
Here, arable land is measured by percentage of the total area. fUSSR is former Soviet Union.

There is a striking difference between Asia’s small grain farms and large western farms in corn and cattle agri-business. Neo-classical economics simply ignores the constraints of natural resources and ecological environment, while global warming raises the issue of sustainable development. Our theory of metabolic growth reveals the link between culture and technology (Chen 1987, 2014).

Generally speaking, an individualist culture is deeply rooted in a resource-intensive and labor-saving technology, while a collectivist culture is associated with resource-scarcity and a population-dense environment. Their economic implication can be explained by the population-resource relation under ecological constraints. In history, we observe that colonialist culture is characterized by risk-taking behavior, while traditional culture is characterized by risk-aversion behavior (Fig.5).




(a). Risk-aversion behavior.



(b). Risk-taking behavior.

Fig 5. Risk-aversion and risk-taking behavior in market-share competition for new resources when technology outlook is uncertain.

The species competition under ecological constraints can be modified with a different culture factor. Even under the same resource constraint, the equilibrium population size is different for different culture.

$$n^*_{a<0} < n^*_{a=0} < n^*_{a>0} \qquad (3)$$

Here, the culture factor $a$ is a measure of risk orientation. If $a > 0$, it is a measure of risk-aversion or collectivism. If $a < 0$, it is a measure of risk-taking or individualism. The case $a$=0 implies risk neutrality.

According to Eqn.(3), the resource utilization rate of the collectivist 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 collectivist 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). This difference is visible between Western individualism and Eastern collectivism. 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).

Wallerstein once observed a historical puzzle that history looked to be irrational (1974): In the Middle Ages, China's population was near twice that of Western Europe while China's arable land was much less than Western Europe. According to the rational choice theory, China should have expanded its space while Europe should have increased in population. But the historical behavior was opposite!

Culture plays a key role in the technology catch-up game. The Western mode of industrialization had great success in the past three hundred years when resource utilization was far below ecological constraints. However, the Western mode is facing increasing challenges of ecological crises and global warming. That is why emerging countries are exploring different modes that are compatible with their environment and sustainable in history. If their learning speed is high enough, like with China and India, they may win the technological competition with developed countries. The metabolic growth theory indicates a new scenario in technology development and global competition for market-share and sustainable resources.

Now, we have a new perspective in understanding the changing international order. For the exogenous growth theory, the regional development speed will converges towards the population growth rate regardless of their initial conditions. For endogenous growth theory, rich and poor countries will face an increasing gap between them if technological knowledge is accumulative. For metabolic growth theory, the competition outcome for leaders (developed countries) and followers (developing countries) is not certain, it depends on innovation and learning speed and their resource scale. Therefore, the evolutionary perspective of metabolic growth is richer and more sophisticated than the equilibrium perspective.

## III. Conclusion: New Theoretical Framework and Evolutionary Thinking

Economics has more similarity with biology than mechanics (Marshall 1920). The neo-classical model of the demand-supply equilibrium is a picture for a pre-industrial economy without revolutionary technology advancement and global competition. The 2008 financial crisis reveals pitfalls of linear-equilibrium thinking and limits of monetary-fiscal policy in structural adjustment.

First, methodological advancement in complexity science is changing our way of thinking not only in natural science, but also in economic and social sciences. A nonlinear and non-equilibrium framework is essential for understanding living and social systems (Prigogine 1980, Chen 2010). Linear and equilibrium models in neoclassical economics simply describe a static market and closed economy, which is far from the modern economy with revolutionary technology, social interaction, and global competition. Endogenous business cycles, regime switching, and financial crises can be explained by the unified theory of population dynamics and market-share competition under ecological constraints. The so-called efficient market is only an extremely simplifying case when nonlinear interaction and herd behavior can be ignored. The more complicated situation with nonlinear interaction and social psychology can be better understood and monitored by the population model of birth-death processes and high moment representation.

Second, neo-classical and metabolic economics implies different goals and tools in economic policy. Neoclassical economics assumes that the market is self-stabilizing; therefore laissez faire policy is optimal under any situation. This belief was shattered by this financial crisis. In contrast, metabolic growth theory emphasizes the role of technology competition under resource constraints. Old technology is constantly replaced by new technology that is the very foundation of economic complexity and non-equilibrium dynamics. Economies are more like organisms rather than calculating machines. Organisms may be healthy or sick, which depends on environmental impact and development stage. Government policy plays different roles at different stages and situations in technology life cycles. For example, public support to R&D is essential at the infant stage of technology, industrial policy is crucial at the growth stage, competition policy is important at the mature stage, and social policy is much needed in case of declining industries. The mixed economy with diversified industries is vital for a sustainable economy. Economic players have to adapt to their specific environment and historical conditions. There is no standard economic recipe for all problems. This is a common understanding in a changing world, since economic complexity implies social diversity.

Third, structural analysis in a biological perspective is more useful than equilibrium analysis of demand and supply in dealing with technology transition and economic crisis. Economic structure can be better studied by the three-level framework of micro-meso-macro economy. The Principle of Large Numbers indicates the clear link between competition policy and macro stability. The liberal policy for the last three decades in the States led financial concentration that is the structural root of the 2008 financial crisis.

Fourth, human nature is to be a social animal with physical and ecological constraints. There is a trade-off between system complexity and structural stability (Chen 1987, 2014). The Western mode of division of labor is based on labor-saving and resource-intensive technology that is facing increasing stress under ecological crisis and global warming. The development of green technology will change the current mode of production and consumption as well as economic institution. The equilibrium paradigm implies a convergent process in social evolution, while nonlinear and non-equilibrium dynamics indicate a two-way evolution towards biodiversity and economic vitality. We are in a historical turning point for a new world of sustainable economy and diversified civilizations.

Finally, the new science of complexity and non-equilibrium physics provides new tools for integrating economic insights from Smith, Malthus, Darwin, Marx, to Schumpeter, Keynes, and Minsky. We are developing a unified theory of complex evolutionary economics.

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