collectivist culture while risk-taking behavior as an individualist culture in learning strategy. Our inspiration comes from the perspective of cultural anthropology. Many observers attribute high innovation in the U.S. to American individualism, while rapid copying technology in Japan may relate to their collectivist culture (Kikuchi 1981).

4.2 Resource-Saving and Resource-Consuming Culture

The equilibrium rate of resource utilization is:

$$\frac{n^*}{N} = \frac{(1 - \frac{r}{Nk})}{(1 - \frac{ra}{Nk})} \tag{7a}$$

$$n^*_{a<0} < n^*_{a=0} < n^*_{a>0} \tag{7b}$$

From Eqn.(7b), 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!

"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. . . "

This historical puzzle can be solved when we consider the link between a culture strategy and an agriculture structure. China's staple food is rice, which is a labor-intensive but land-saving technology. Diary food plays an important role in European culture. Dairy agriculture is a land-intensive and labor-saving technology. In response to increasing population pressures, China is used to increasing labor input for increasing grain yield, while Europeans are used to seeking new land for improving their living standard. That is why Chinese philosophy used to emphasize the harmony between men and nature, while Western strategy used to conquer nature. This is a cultural perspective to Needham's question. By the same reason, we can understand why Asian country's saving rates are much higher than in the West. Preparing for an uncertain future rather than seeking current happiness is deeply rooted in Chinese culture and history.

In this regard, the former Soviet Union was close to western individualism, since they had a strong motivation in expansionism.

When we study civilization history, we find that famers are more collectivist than nomads and sailors. Japanese culture is highly collectivism even it's city residents. However, Japanese foreign policy is more closely compared to the British Empire because it is an island country with a strong naval tradition. New technology in shipbuilding and navigation opened new resources in foreign trade and colonialism in addition to limited arable land.

4.3 Market Extent, Resource Variety, and Economy of Scale and Scope

We can easily extend our model from two technologies (species) to many technologies (species). In an ecological system with L technology (species), their resource limits (carrying capacities) are $N_1, N_2, ..., N_L$. The economy of scope and scale can be integrated into a complex system of coupling logistic-type competition equations. A scale economy is related to the market extent or resource limit N_i, while a scope economy can be described by the number of technologies (species) L . The degree of the division of labor can be characterized by the biodiversity, i.e. the coexistence of competing technologies.

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

$$\frac{dn_1}{dt} = k_1 n_1 (N_1 - n_1 - \beta n_2) - r_1 n_1 (1 - \frac{a_1 n_1}{N_1}) \qquad (8a)$$

$$\frac{dn_2}{dt} = k_2 n_2 (N_2 - n_2 - \beta n_1) - r_2 n_2 (1 - \frac{a_2 n_2}{N_2}) \qquad (8b)$$

Here n_1, n_2 is the number of adopters in technology (species) one and two respectively. For simplicity, we only discuss the simplest case when $\beta = 1$ under complete competition.

We may solve Eq. (8) in the similar way in solving Eq. (2). The replacement condition and the co-existence condition are (9a) and (9b) respectively:

$$C_2 > \frac{(1 - \frac{a_2 r_2}{k_2 N_2})}{\beta} C_1 \quad \text{for species 2 replace species 1.} \qquad (9a)$$

$$\frac{\beta}{(1 - \frac{a_1 r_1}{k_1 N_1})} < \frac{N_2 - \frac{r_2}{k_2}}{N_1 - \frac{r_1}{k_1}} < \frac{1}{\beta}(1 - \frac{a_2 r_2}{k_2 N_2}) \qquad (9b)$$

4.4 The Impact of Environmental Fluctuations

The next task is studying the impact of environmental fluctuations to system stability. The problem of a nonlinear dynamical system under random shocks can be solved by the Langevin equation and Fokker-Planck equation (May 1974, Chen 1987, 2010). Here, we only consider a simple case where a stream of random shocks adds to the resource limit of one technology N . The realized equilibrium size X_m would be reduced by a fluctuating environment with the variance of σ^2:

$$X_m = N\frac{(1-\frac{r}{kN}-\frac{k\sigma^2}{2N})}{(1-\frac{ra}{kN})} \qquad \text{when } \sigma < \sigma_c = \sqrt{\frac{2N}{k}(1-\frac{r}{kN})} \qquad (10a)$$

$$X_m = 0 \qquad \text{when } \sigma > \sigma_c = \sqrt{\frac{2N}{k}(1-\frac{r}{kN})} \qquad (10b)$$

If there exists some survival threshold in population size, then the collectivism has a better chance of surviving under external shocks because it has a larger population size.

Environmental fluctuations will reduce the resource limit of the equilibrium state, as seen from Eq. (10a). When fluctuations are larger than the threshold, the technology would die as in Eq. (10b). That is why some ancient civilizations disappeared due to a natural disaster or war. Economic development needs social stability.

When we consider environmental fluctuations to many species, we may realize the importance of biodiversity. Regional specialization effectively increases concentration of risk. Mass production in agriculture also intensifies the application of chemical fertilizer and pesticide. In another words, economy of scope is helpful for maintaining biodiversity.

4.5 Trade-Off between Stability and Diversity and The Generalized Smith Theorem

For a more general case with many technologies, increasing the number of technologies will reduce system stability (May 1974). There is a trade-off between diversity and stability. Smith did not realize the importance of science and technology that introduces new resources and new markets, since the Industrial Revolution was still in its infancy during his time. We propose a generalized Smith Theorem (Chen 2005, 2010) as the following:

The division of labor is limited by the market extent (resource limit), bio-diversity (number of resources), and environmental fluctuations (social stability).

Neoclassical growth models have an one-way evolution to convergence or divergence under linear stochastic dynamics. There may be a two-way evolution (or co-evolution) process towards complexity or simplicity in division of labor under nonlinear evolutionary dynamics. When social stability is high and new resources keep coming, the system may develop into a complex system, like the Industrial Revolution in the past. However, when social turmoil is high or resources are used up due to over population, a complex system may break down into a simple system, such as the collapse of the Roman Empire in the Middle Ages. Even in the modern era, industrial society coexists with traditional society and even primitive tribes. The basic cause is the interactions among population, environment, and technology.

4.6 Competition Scenario between Individualism and Collectivism and Dynamical Picture of Schumpeter's Creative Destruction

There is a popular belief that individualism would beat collectivism, since individualism is more innovative in technology competition. However, there are three possibilities under complete competition:

(i). Both species are individualists. From Eq. (9b), two individualist species may coexist. Competition between individualists would increase system diversity. The city-states in ancient Greece and Renaissance Italy are examples.

(ii). Both species are collectivists. Based on Eq. (9b), two collectivist species cannot coexist, 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 purely collectivist society.

(iii). One individualist and one collectivist. This is the general case when competition is a game of uncertainty. This is a mixed economy with one collectivist and one individualist species. One interesting feature is that the stability of a mixed system is higher than the liberal system with two individualists. We may extend this result to a case with more than two species. This scenario is perceivable when we compare the two-party political system in the Anglo-Saxon countries and the multi-party political system in continental Europe.

What would happen when an individualist species competes with a collectivist one? They may coexist, or one replaces another, depending on their resource limits, learning ability, and cultural factors. We may add a few discussions to this case.

If two species have equal resources ($N_1 = N_2$), then, the collectivist species will replace the individualist one. If we compare (8a) with (3a), the late-comer in a collectivist culture may beat the individualistic leader even if $C_2 \le C_1$ when $\beta \approx 1$ and $0 < a_2 \approx 1$. This is the story of how Japan and China caught up with the West in the 1970's and 2010's respectively. A collectivist culture can concentrate its resources on a "catching-up" game. The success or failure of the industrial policy depends on the government's ability for mobilizing strategic resources on emerging technologies, a typical feature of learning by imitating in the catching-up game.

The survival strategy for an individualist 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 (1939) that 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 collectivist in the existing markets. This picture of changing economic powers is different from the permanent division between early-movers and late-comers in endogenous growth theory. Our model of learning strategy can be applied to an arm race or corporate strategy if the relevant data are available.

5. Issues in Methodology and Philosophy

There are several issues in methodology and philosophy. Keynes once remarked (1936):

> "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 a non-Euclidean geometry. Something similar is required today in economics. "

Our population dynamics is an alternative framework to an optimization approach in neoclassical economics. This paradigm change induces fundamental shifts in the following issues.

5.1 Real vs. Monetary Economy

Neoclassical growth theory is a monetary system, where capital and population are driving forces in economic growth. Our population dynamics is a real system, where resource and population play key roles in economic growth. The theoretical issue is the relation between the real and virtual (monetary) economies.

Historically, the core concepts in classical economics started from land, population, and capital. In neoclassical economics, there is an increasing trend of virtualization in economic theory. One important lesson from the 2008 financial crisis is the danger of over-expansion of the virtual economy in developed countries (Johnson 2009, Chen 2010).

According to BIS (Bank of International Settlement) data, the size of the global derivative market in Dec. 2012 was $632.6 trillion U.S. dollars, which is nearly 9 times the world total production or 40 times the U.S. GDP. There may be a dangerous link between virtualization in economic theory and virtualization in the U.S. economy.

5.2 Equilibrium vs. Non-equilibrium Mechanism

The optimization approach can only apply to an equilibrium system in a closed economy. There is a fundamental problem for general equilibrium models in the endogenous growth theory. In neoclassical economics, price plays a central role in creating equilibrium in the market exchange. The profit for a representative firm should be zero in the general equilibrium model. It means that capital cannot grow in a closed economy under general equilibrium. Clearly, microfoundations theory of endogenous growth fails to provide a consistent theory in capital accumulation and technology progress (Chen 2002).

In our metabolic growth theory, we did not introduce price factors into population dynamics, since there is no unique (linear) price in a non-equilibrium system in a market-share competition. In Section 3.4, profit opportunity mainly exists at the second growth stage. However, there is a trade-off between short-term profit and long-term market-share. You cannot calculate its optimal value when future market shares and competitor's strategies are unknown. That is why vision and strategy matters in technology competition. Capital loss mainly occurs at the fourth decline stage. The cost of the 2008 financial crisis was about 13 trillion U.S. dollars. The smooth picture of capital growth in neoclassical theory abstracts out the uncertainty in technology advancement from the linear-equilibrium perspective. Our scenario is more realistic than the neoclassical model in understanding firm behavior. In another words, there is no empirical evidence of marginal cost pricing. But there are abundant cases of strategic pricing in marketing practice (Shaw 2012).

Another example is the equilibrium trap of the so-called rebalancing policy promoted by Federal Reserve Chairman Ben Bernanke. China was more successful in dealing with the 2008 financial crisis in a non-equilibrium approach, which was characterized by large investments in infrastructure, such as high-speed trains, and new technology, including new energy and new materials. The U.S. Congress refused any structural reform and single-mindedly relied on the Federal Reserve policy of printing money. The European Union and Japan are dealing with the debt crisis by implementing limited fiscal and monetary policies.

Both neoclassical economics and Keynesian economics pay little attention to economic structure. The down-sloped IS curve theory is wrong in an open economy under non-equilibrium conditions. If you lower the interest rate, there are three, not just one, possibilities in the globalization era; In a healthy economy with growth prospects, lower interest rates will increase investment and production; In an uncertain economy, investors prefer to hold cash or reduce existing debts; In a sick economy, lower interest rates may cause large capital flight to foreign economies promising better returns. We found solid evidence of color chaos from macro and financial indexes (Chen 1996, 2005, 2008). The linear causality in the IS-LM scheme is simply an equilibrium illusion in a non-equilibrium world with economic complexity (Chen 2010).

5.3. Linear vs. Nonlinear Thinking

Linear thinking is the common feature of neoclassical growth models. Robert Solow was clearly aware of not only the symptom, but also the cause in neoclassical growth theory (Solow 1994). For example, increasing returns to scale would lead to an explosive economy, while diminishing returns to scale would generate a convergence trend that is not shown in historical data. Each innovation kills its predecessors in the Aghion and Howitt model of "creative destruction" (1992). In reality, many innovations are complementary with predecessors. The model of learning by doing simply ignores the important role of R&D.

From our perspective, the shortcoming of neoclassical economics is linear thinking. Once we adopt the nonlinear perspective, even with the simplest logistic model, all troubles in neoclassical growth theory can be easily solved. For example, Schumpeter's creative destruction does not mean non-coexistence between old and new technology. Complementary technologies can emerge if their competition coefficients are small.

Any technology or industry has a life cycle, or more precisely, a wavelet. Let us consider the textile industry at a mature stage in developed countries. Certainly you have diminishing returns in capital if you continue to invest in the U.S., but you may still have increasing returns if you invest in Asia. There was a convergence trend when low technology moved from advanced to backward economies in the 1970's and 1980's. However, when the computer and Internet industries emerged in the West, foreign investment moved back to developed countries in order to catch the new opportunity of increasing returns to capital for new technology at the growth stage. You may have seen a temporary diverging trend between rich and poor countries in the 1990's. Why did China rapidly catch up to Asian tigers in the manufacturing industry in the 1990's and 2000's? Simply because China's economic scale and market extent was much larger than in Asian tigers and East European countries.

The policy implications of neoclassical growth theory for economic growth are dubious. The exogenous growth theory emphasizes the roles of population growth and capital accumulation. The endogenous growth theory further enhances the role of knowledge capital. They do not understand that these factors can be double-edged swords.

During a visit to Egypt last summer, it was observed that the current turmoil in the Mid-East is deeply rooted in high population growth, limited food supply, and high unemployment rate among young educated people. Egypt's population growth rate is four times that of China, but the GDP growth rate is about one fourth that of China. Historically, Egypt was a main exporter of grain to Europe and now is a big importer of grain from the U.S. Egypt did not make major investments in family planning and farmland reconstruction like China in the past. Both the military regime and elected governments have little means to solve the resource-population problem on a short-term. The U.S. economy faces another problem. According to CIA data, the school life expectancy is 17 years in the U.S., UK, and Spain, 16 years in Germany, and 12 years in China and Egypt. According to endogenous growth theory, you may expect U.S. manufacturing should better compete with Germany and China. However, Steven Jobs, the late CEO of Apple Inc., bluntly told President Obama in 2012 that the U.S. stopped to train middle-level engineers on a large scale (Barboza et al 2012). China once faced the shortage of skilled workers and industrial technicians. They solved the problem by introducing the German system of technical schools, not just the American system of higher education. Again, knowledge structure matters more than aggregate stock in economics. By introducing nonlinear interaction into growth theory, we have a more proper policy for economic growth and development.

5.4 Theory vs. Simulation

There is a big difference between theoretical models and computational simulations. Theory is aimed to catch general features from a wide range of observations at the cost of abstracting out many details, while simulation seeks to describe many details from a specific object at the cost of generalizing to other objects. In this regard, our market-share competition model is a theory, while system dynamics, as well as econometrics, are different approaches in economic simulation (Forrester 1961, Meadows et al. 2004). Competing simulation models are tested by empirical data. Competing theories in science are tested by controlled experiments. In economics, controlled experiments are limited in scale and scope. Economic schools of thought are mainly tested by historical trends and events. For example, the Great Depression shook the faith in the self-stabilizing market, so that Keynesian economics rose to replace classical economics in mainstream economics in the UK and the U.S. The Lucas theory of microfoundations and rational expectations became popular in the West during the stagnation era in the 1970's, and are now facing serious challenges from the 2008 financial crisis.

The exogenous theory of growth won a great deal of attention in the 1950's, which was the golden era for the U.S. after the WWII. The endogenous growth theory attracted a lot of attention during the hype of the dot.com boom and the so-called knowledge economy. After the failure of the Iraq war and the 2008 financial crisis, people started to doubt the convergence theory when so many countries were still in a poverty trap, and the sustainability of a developed economy. Our theory of metabolic growth is a mathematical way of new thinking in economics and world history. We share a similar view of anthropologists and historians that changes in climate and environment shaped by the history of civilizations (Morris 2010).

6 Conclusions

Technology advancement and resource exploitation is the driving force of an industrial economy. How to understand the dynamic interaction between technology, resources, and population is a fundamental issue in economics and history. Both exogenous and endogenous growth theory puts abstract capital as the driving force of economic growth but takes out the critical role of resources. In this regard, neoclassical growth theory is a big retreat from classical economists such as Smith and Malthus. Therefore, using neoclassical growth theory, it is hard to understand development mechanisms, environmental crisis, and recurrent cycles.

Our work based on population dynamics brings back the central idea of Adam Smith and Thomas Malthus that the division of labor is limited by the market extent and resource capacity. Nonlinear population dynamics is an alternative framework for economic dynamics. We made several contributions that are beyond the scope of neoclassical growth theory.

First, industrialization is characterized by a sequence of discoveries of new resources and new markets. Material wealth is associated with both scale (resource capacity) and scope (number of resources) economy. Therefore, material wealth in human society is closely linked to biodiversity.

Second, Schumpeter's "long waves" and "creative destruction" can be described by the rise and fall of technology wavelets that are derived from population dynamics (Schumpeter 1934, 1939, 1950). The observed growth cycles with nonlinear trends and irregular cycles from macro indexes can be interpreted as the envelopment of aggregated logistic wavelets (Prigogine, Allen, and Herman 1977), which build a link between technology wavelets at the industry level and business cycles at the macro level.

Third, structural unemployment is rooted from excess-capacity under technology competition. Unlike the microfoundations model in business cycle theory, this is the meso foundation of macro unemployment and recurrent cycles (Lucas 1981, Chen 1996a, 1996b, 2002). Another source of structural unemployment is decreasing biodiversity, which is essential for full employment and sustainable development.

Fourth, we have a better understanding of the nature of knowledge and the nonlinear patterns in economic growth. Exogenous growth theory treats technology advancement as a series of random shocks. Endogenous growth theory asserts that knowledge is an accumulation process. We uncover the metabolic nature in knowledge development. Modern technologies are shaped by scientific revolution. Paradigm changes and interruptive technologies indicate wavelike movements in science and technology development, which is radically different from the random walk in neoclassical models (Kuhn 1962). From the nonlinear perspective, we can see changing dynamic returns and co-evolution of organization and institution during the technology life cycle.

Fifth, the culture factor is introduced into learning competition. Risk-taking individualism and risk-aversion collectivism are different strategies for survival under a market-share competition. Different modes of division of labor are shaped by resource constraints and culture in history.

Sixth, we developed the generalized Smith Theorem that the division of labor is limited by the market extent, number of resources, and environmental fluctuations. There is a trade-off between system stability and system complexity. Economic evolution is a nonlinear two-way dynamic towards diversity and non-equilibrium.

Finally, we pave the way for a unified theory in economics including micro, macro, finance, and institutional economics based on evolutionary complex dynamics. We pointed out that a neoclassical framework is not proper for an industrial economy, since the Hamiltonian system is a closed system in nature. Neoclassical concepts such as perfect information, rational expectations, noise-driven cycles, zero-transaction costs, infinite life, IS curves, long-run equilibrium, and unlimited growth, are utopian ideas that go against basic laws in physics and are non-observable in reality (Chen 2005, 2007, 2008, 2010). People are social animals with life cycles and interactions. We developed a nonlinear oscillator model for color chaos (Chen 1996), the birth-death process for macro and financial fluctuations (Chen 2002), and a logistic competition model for metabolic growth (Chen 1987, 2008). We show that population dynamics is a useful model for a dissipative economic system in an open economy. The wavelets representation and these nonlinear models are building blocks for a unified theory of complex evolutionary dynamics in micro, meso, macro and institutional economics (Chen 2010). The new science of complexity develops new tools in nonlinear dynamics and non-equilibrium mechanisms (Nicolis and Prigogine 1977, Prigogine 1980, 1984), which are essential for understanding economic development and social evolution.

Economists used to think that economic evolution is hard to formulate by mathematical language (Mirowski 1989). This is not true in the era of complexity science. Historical development can be well described by nonlinear and non-equilibrium dynamics. The key is finding the proper link between theory and observations.

Acknowledgements

The author thanks Peter Allen, Wolfgang Weidlich, Edmond Phelps, Joseph Stiglitz, James Galbraith, Ulrich Witt, Justin Lin, Wolfram Elsner, Andreas Pyka, Laura Tyson, Zhengfu Shi, Yinan Tang, Huajun Li, and Vivian Chen for their stimulating discussions.

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