Metabolic Growth Theory:
Market-Share Competition, Learning Uncertainty, and Technology Wavelets

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Journal of Evolutionary Economics, 24(2), 239-262 (2014).
DOI 10.1007/s00191-014-0341-0

Abstract

Both exogenous and endogenous growth theories in neoclassical economics ignore the resource constraints and wavelike patterns in technology development. The logistic growth and species competition model in population dynamics provides an evolutionary framework of economic growth driven by technology wavelets in market-share competition. Learning by doing and knowledge accumulation ignores the interruptive nature of technology advancement. Creative destruction can be understood by using knowledge metabolism. Policies and institutions co-evolve during different stages of technology cycles. Division of labor is limited by the market extent, numbers of resources, and environment fluctuations. There is a trade-off between the stability and complexity of an ecological-industrial system. Diversified patterns in development strategy are shaped by culture and environment when facing learning uncertainty. The Western mode of division of labor is characterized by labor-saving and resource-intensive technology, while the Asian and Chinese modes feature resource-saving and labor-intensive technology. Nonlinear population dynamics provides a unified evolutionary theory from Smith, Malthus, to Schumpeter in economic growth and technology development.

Key words: growth theory, market-share competition, technology wavelet, learning uncertainty, knowledge metabolism.
JEL Classification: C30, E37, D83, L50, O00

1. Introduction

There are two conflicting views of technology development. Neoclassical growth theories consider technology progress as a smooth trajectory with perfect foresight, which can be described by log-linear models in the form of Cobb-Douglas function (Solow 1957, Romer 1986, Aghion and Howitt 1998, Dasgupta 2010, Kurz 2012). Economic historians recognize wavelike patterns and revolutionary changes in industrial economies (Schumpeter 1939, Toffler 1980, Ayres 1989, Rostow 1990). We will develop the second approach in this article by introducing nonlinear population dynamics into market-share competition.

The equilibrium perspective prescribes a uni-directional causality to convergence (exogenous growth theory in capital accumulation) or divergence (endogenous growth theory in knowledge accumulation) in economic growth. However, biological evolution and industrial revolution reveals a clear pattern of dynamic metabolism and complex patterns in a two-way evolution towards convergence and/or divergence in different periods and regions.

Historically, it was Malthus, an economist, whose theory of resource constrain for population growth inspired Darwin's theory of biological evolution (Malthus 1798, Darwin 1859). The logistic model and the prey-predator model were introduced in modeling business cycles (Goodwin 1967, Samuelson 1971, Day 1982). We will consider a new factor of culture strategy when facing learning uncertainty, which is useful in understanding different modes of division of labor in historical development (Chen 1987).

In this article, we will raise two basic issues in growth theory.

First, what is the nature of knowledge? Endogenous growth theory offers a static picture of knowledge accumulation through learning by doing (Arrow 1962). This theory implies an increasing polarization between rich (early-movers) and poor (late-comers). This picture is not compatible with world history, with the rise and fall of nations and civilizations.

Second, how can one understand the roots of global warming and the ecological crisis? The neoclassical Cobb-Douglas production function in AK model implies unlimited resources. This framework cannot address the contemporary issues of the ecological crisis and global warming.

It is known that industrial economies are driven by sequences of new technologies, such as coal, petroleum, electricity and nuclear energy, which exploit new resources. Wavelike technology development can be described by population dynamics with resource constraints, notably the S-shaped logistic curve and the Lotka-Volterra model for species competition (Pianka 1983, Nicolis and Prigogine 1977). Schumpeter's long waves and creative destruction can be described by metabolic movements of logistic wavelets. Culture plays a strategic role when facing learning uncertainty. The Western mode of the division of labor is characterized by labor-saving and resource-intensive technology, while the Chinese mode is mainly driven by resource-saving but labor-intensive technology.

This article is organized by the following: Section 2 discusses some basic facts on resource disparity and uneven growth in world history that raises challenges to growth theory. Section 3 develops the logistic model of growth and technology competition under resource constraints (Chen 1987). The implications of nonlinear solutions, including the S-shaped curve and the logistic wavelet, are discussed from the perspective of evolutionary dynamics. Section 4 introduces the cultural factor in learning strategy when facing a new but uncertain resource or market. The division of labor is limited by the market extent, number of resources, and environmental fluctuations. There is a trade-off between stability and diversity. Section 5 discusses historical puzzles in civilization bifurcation that can be explained by our approach (Chen 2008, 2010). Section 6 addresses basic issues in economic methodology. Section 7 concludes with a comparison between the equilibrium and evolutionary perspectives in growth theory.

2. Uneven Economic Growth and Limits of Neoclassical Growth Theories

The Solow model of exogenous growth predicted a convergence trend in economic growth based on the assumption of constant returns to scale (1957) while the Romer model of endogenous growth claimed a divergence trend based on increasing returns to scale in knowledge accumulation (Romer 1986, Arrow 1962, Lucas 1988). However, observed patterns in the world economy are more complex than the predictions of neoclassical growth models (see Table 1 and Table 2).

Table 1. Historical Statistics (1913-2001)

Annual average compound rate of GDP growth

	WEuro	EEuro	Asia	US	Japan	fUSSR	China
1913-50	1.19	0.86	0.82	**2.84**	**2.21**	2.15	-0.02
1950-73	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**

Data source: Maddison (2007). WEuro means western Europe; EEuro as eastern Europe, fUSSR as the former Soviet Union. Here, Asia data excluded Japan.

Table 2. Uneven Growth in Globalization

(Annual average growth rate of Real GDP per decade)

Period	1970s	1980s	1990s	2000s
China	**6.2**	**9.3**	**10.4**	**10.5**
Japan	3.8	4.6	1.2	0.7
US	3.2	3.2	3.4	1.6
Germany	2.9	2.3	1.9	0.9
East Asia	4.4	**5.5**	3.3	4.0
L. America	**6.1**	1.5	3.2	3.1
E. Europe	4.4	2.3	-2.0	**4.3**
W. Europe	3.1	2.3	2.1	1.1
Australia & New Zealand	2.8	2.9	**3.6**	3.0
World	3.8	3.1	2.8	2.5

(Data source: United Nations Statistics)

We can see that the U.S. had the highest growth rate between 1913-1950, Japan from 1950-1970, and China from 1970-2010. We did not see a rigid convergent or divergent trend for each region or from a cross-country comparison. Instead, we see changing trends with the rise and fall of nations.

It is known that the rise of the West was driven by resource expansion under colonialism (Pomeranz 2000). In terms of per capita arable land, East Asia including Japan and China has much less arable land compared to Western countries (Table 3).

Table 3. Cross Country Comparison in 1993 (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.

There is a striking difference between Asia's small grain farms and large western farms in corn and cattle agri-business. Obviously, an individualist culture is deeply rooted in a resource-intensive and labor-saving technology, while a collectivist culture is associated with resource-scarce and a population-dense environment. The role of culture and resource in the modernization catch-up game will be discussed in Section 5. Our observation on patterns in resource and population started from a cross-country comparison, which can be extended to any industrial analysis if relevant data are available.

3. Logistic Model of Limited Growth and Species Competition

The Cobb-Douglas production function in neoclassical economics can be transformed into a log-linear function, which means unlimited growth without resource limits or market extents. The studies of resource limits need the development of nonlinear dynamics.

3.1 Limited and Unlimited Growth in Economic Dynamics

Adam Smith clearly stated in his third chapter of the Wealth of Nations that the division of labor is limited by the market extent (Smith 1776, 1981). This statement was called the Smith Theorem by George Stigler (1951). Malthus further pointed out that population growth is limited by natural resources (Malthus 1798).

The Smith concept of "market extent" and the Malthus idea of "resource constraint" can be described by carrying capacity N* in the nonlinear logistic model of population growth. When applying the ecological model to economic growth, we need to change the name of corresponding variables. In the following discussion, we will put the original name in theoretical ecology into brackets after the economic variable, so that readers can clearly understand the original meaning and its economic meaning.

From the demand-side perspective, n is the number of buyers (population) and N* the market extent (population size), which is a function of income distribution. Here, the market extent is associated to population size with affordable income.

From the supply-side perspective, n is the output and N* the resource constraint, which is a function of existing technology and cost structure. For example, grain yield can be increased by the application of irrigation and fertilizer or new products like corn and potatoes historically.

The simplest model of limited growth is the logistic model with a quadratic function in evolutionary ecology (Pianka 1983):

$$\frac{dn}{dt} = f(n) = kn(N^* - n) \qquad (1)$$

Here n is output (population), N^* is the resource limit (population size), k is output (population) growth rate.

The logistic model has a varying dynamic economy of scale:

dynamic increasing return for $f' > 0 \; when \; 0 < n < \frac{N^*}{2}$ (2a)

dynamic diminishing return for $f' < 0 \; when \; \frac{N*}{2} < n < N*$ (2b)

The logistic model is the simplest form of nonlinear dynamics. The reflection point may shift from the middle point, when *f(n)* is not a quadratic function.

In comparison, the AK model in neoclassical growth theory has fixed returns to scale without resource limits. Therefore, neoclassical firm theory is not capable of understanding changing economies of scale (Daly and Farley 2010).

The logistic model is also called the Verhulst equation in theoretical ecology (Pianka 1983). Its discrete-time version may produce the simplest chaos regime with only one variable. Deterministic chaos in discrete-time can be called "white chaos", since its frequency spectrum looks like white noise (May 1974, Day 1982, Chen 2010). Its continuous-time solution is a S-curve. The graphic patterns of unlimited (exponential) growth and limited (logistic) growth are shown in Fig. 1.

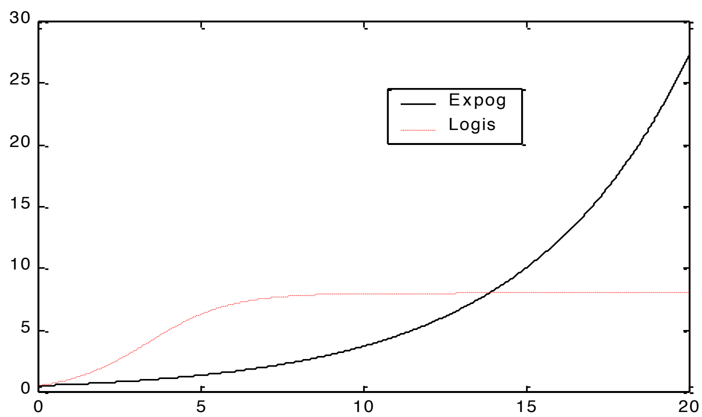


Fig. 1. Unlimited (exponential) vs. limited (logistic) growth.

When we adopt the logistic model in economic theory, our analytic unit is technology or industry. If the resource limit is arable land, our analytic unit can be a region or a state. In empirical analysis, the meaning of market extent or resource capacity depends on available data.

The logistic growth pattern can be clearly observed from sector industrial data, such as the output ratio to GDP in the U.S. automobile industry in Fig. 2 (Chen 2010).

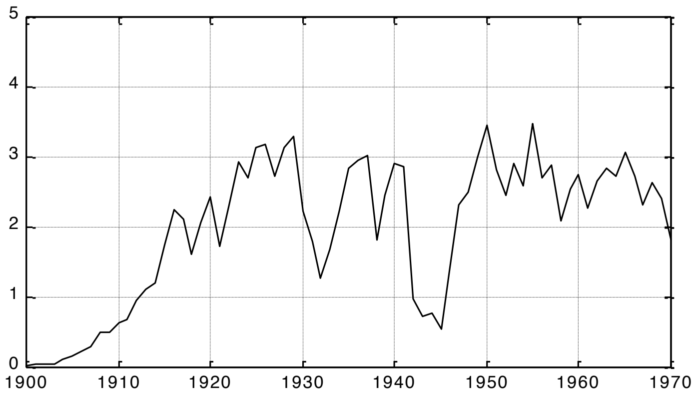


Fig. 2. The output ratio to GDP in the U.S. automobile industry.

We can see that the U.S. auto industry took off between the 1900's and the 1920's, and reached the saturation stage before the 1930's. The S-shaped growth curve can be observed in firm and industrial growth in sector analysis.

3.2. Market-Share Competition Model in Open Economy

Now, we move from one technology to more technologies in a market-share competition. The simplest resource competition model is a two-species competition model or the Lotka-Volterra equation in theoretical biology (Pianka 1983).

$$\frac{dn_1}{dt} = k_1 n_1 (N_1 - n_1 - \beta\, n_2) - R_1 n_1 \tag{3a}$$

$$\frac{dn_2}{dt} = k_2 n_2 (N_2 - n_2 - \beta n_1) - R_2 n_2 \quad (3b)$$

Where n_1, n_2 are output (population) of technology or product (species) 1 and technology (species) 2; N_1 and N_2 their resource limit (carrying capacity); k_1 and k_2 their learning (population growth) rate; R_1 and R_2 their exit (death) rate; β is the competition (overlapping) coefficient in market-share (resource) competition ($0 \leq \beta \leq 1$).

The equations can be simplified by introducing effective resource limits (or an effective resource limit) (carrying capacities)

$$C_i = N_i - \frac{R_i}{k_i}. \quad (3c)$$

Here, we should emphasize the different perspective of technology development between neoclassical economics and evolutionary economics. General equilibrium models only consider features in a closed economy, such as the static model having fixed number of products with infinite life (Arrow and Debreu 1954), or dynamic model with random innovations (Aghion and Howitt 1992). In contrast, population dynamics mainly concerns an open economy, where new technology introduces new resource and new market. Therefore, nonlinear population dynamics is more realistic for industrial economy with interruptive technologies.

Our population dynamics describes a learning competition in facing a new (uncertain) resource. Here, population indicates the number of users of a specific technology. The entry and exit speed of the new technology is described by the learning and exit rates in the learning process. For mathematical simplicity, we put the learning rate at the quadratic term and the exit rate at the linear term. Therefore, the learning mechanism has a stronger impact than the exit mechanism in technology competition.

The meaning of the exit rate can be seen in Eq. (3c). Consider a case of agricultural development. If grain is the only food available for a population, then the exit rate for grain is $R_1=0$, and $C_1=N_1$. However, if a new food, say, potatoes, are introduced, some portion of the population would switch from grain to potatoes, so that the exit rate $R_1>0$, and $C_1 < N_1$. The effective resource limit may be lower than the original land without competition.

The competition coefficient β measures the degree of competition. When $\beta = 0$, there is no competition between the two species. Both technologies may fully grow to reach their resource limits independently.

In neoclassical economics, relative price plays a central role in resource allocation. In an industrial economy, market-share plays a major role in shaping industrial structure. The competition coefficient can be estimated if market-share data is available in marketing research and industrial analysis.

Technology metabolism means the birth of new technology and the death of old technology. Technology competition may have two consequences: (i) old technology is replaced by new technology under condition (4a); or (ii) old and new technologies co-exists under condition (4b).

$$\beta (N_2 - \frac{R_2}{k_2}) = \beta C_2 > C_1 = (N_1 - \frac{R_1}{k_1}) \qquad (4a)$$

$$\beta < \frac{C_2}{C_1} < \frac{1}{\beta} \qquad \text{Here } 0 < \beta < 1 \qquad (4b)$$

Therefore, the new technology will wipe out the old technology if its resource limit is much higher than the old technology.

When two technologies co-exist, both the new and old technologies cannot fully utilize their resource potentials, since their equilibrium output is smaller than their resource limits (5a, 5b, 5c). The cost of creative destruction is the unrealized (excess) capacity.

$$n_1^* = \frac{C_1 - \beta C_2}{1-\beta^2} < C_1 \quad (5a)$$

$$n_2^* = \frac{C_2 - \beta C_1}{1-\beta^2} < C_2 \quad (5b)$$

$$\frac{1}{2}(C_1 + C_2) \leq (n_1^* + n_2^*) = \frac{(C_1+C_2)}{1+\beta} \leq (C_1 + C_2) \quad (5c)$$

For example, technology n_1 would reach full capacity of C_1 in absence of technology 2. After technology n_2 entered the market share competition, there are two possible outcomes for technology n_1: (i) Technology 1 is wiped out by technology 2, so that $n_1=0$ and $n_2=C_2$. The cost of "creative destruction" is the total loss of old capacity C_1. This was the case when the handcraft textile industry was destroyed by machine industry in the early development stage. (ii) Old and new technology coexist, so that both technologies have excess capacity: $(C_1-n_1^*) >0$ and $(C_2-n_2^*) >0$.

Here, species competition model sheds light on market-share competition. For example, if we have market-share data for major firms in computer industry, we may apply our model to marketing competition. If we have relevant data, we may also study arm race among nations.

Frank Knight made the distinction between predictable risk and unpredictable uncertainty (Knight 1921). Risk is often measured by variance in neoclassical econometrics. Here, we have two types of uncertainty: the arrival time of a new technology and the initial condition of a new technology. Therefore, there is no possibility for optimization or rational expectations in technology competition because of unpredictable uncertainty. Path dependence is the essential feature of technology development (David 1985, Arthur 1994).

Keynesian economics has no structural theory for "insufficient aggregate demand". Micro-foundations theory attributes macro fluctuations to household fluctuations in working hours, which is rejected by the Principle of Large Numbers (Lucas 1981, Chen 2002). Now we have a meso-foundation for macro growth cycles: the existence of excess capacity at the industrial level under technology metabolism. The observed costs in terms of excess capacity and related large unemployment are typical forms of dissipative energy or economic entropy (Georgescu-Roegen 1971).

3.3. Technology Life Cycle, Logistic Wavelets and Metabolic Growth

The concept of a product life cycle is widely used in economics and management literature (Vernon 1966, Modigliani 1976). We apply this concept to a technology life cycle. Traditionally, the life-cycle phenomenon can be described by a multi-period model in econometrics. Linear dynamical models, such as a harmonic wave with infinite life and a white noise model with a short life (Kydland 1995), are not proper for a life-cycle model, since a life cycle is a nonlinear phenomenon. The logistic wavelet with a finite life is a simple nonlinear representation for technology life cycles. Schumpeter's long waves and creative destruction can be described by a sequence of logistic wavelets in a technology competition model (Schumpeter 1934, 1939, 1950).

A numerical solution of Eq. (3) is shown in Fig. 3. Without competition, the growth path of technology (species) 1 would be a S-shaped logistic curve. However, the realized output of technology 1 resulting from competition with technology (species) 2 looks like an asymmetric bell curve. We call it the logistic wavelet, which is a result from the competition of new technology. The envelope of the aggregate output shows an uneven growth path that mimics the observed pattern of a time series from macroeconomic indexes.

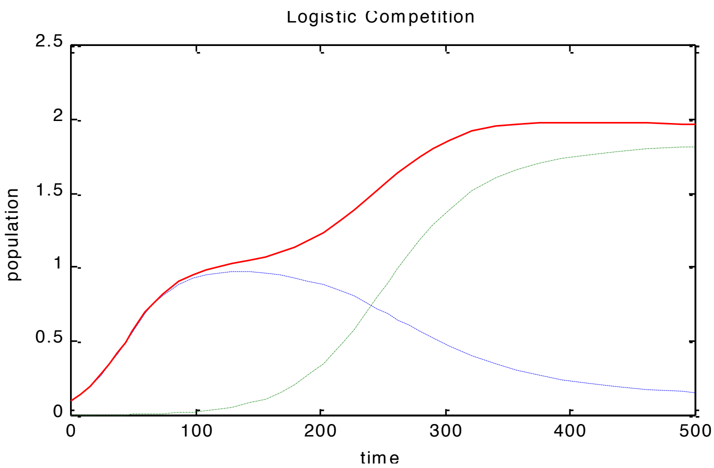


Fig. 3. Metabolic growth characterized by technology competition in Eq. (3). The old technology (blue dashed

line) declines when new technology (green dot and dash line) emerges. The output envelope (red solid line) is the sum of their output of all technologies. Here, $\beta = 0.4$, $C_2 / C_1 = 2$. The units here are arbitrary in computational simulation.

The wavelet representation can be applied in analyzing the lifecycle of products, firms, technologies, and nations (Eliasson 2005). The traditional life-cycle model in econometrics takes the form of discrete-time with linear dynamics (Browning and Crossley 2001), while the wavelet model is a continuous-time model in nonlinear dynamics. The time scale of the logistic wavelet varies between product life cycles from several months to Kondratieff long waves over several decades.

3.4 Capital and Institution Co-evolution during the Four Stages of Logistic Wavelet

The metabolic growth model provides a theoretical framework for capital movement and institutional co-evolution with the rise and fall of technology wavelets. We may divide the logistic wavelet into four stages: I. Infancy, II. Growth, III. Maturation, IV. Decline.

Neo-classical theory treats capital as a smooth growing stock that fails to explain the endogenous causes of business cycles and recurrent crisis.

The wavelet model of technology provides an endogenous mechanism of capital movement and policy changes.

At the first stage of infant technology, some survival threshold may exist. Before reaching this threshold, it is hard for an infant technology to survive. Some protection in intellectual property and foreign trade may be helpful for infant industries. Private investors are reluctant to invest in a new technology due to great uncertainty. R&D of new technology is mainly sponsored by the public sector and non-profit universities. For example, the Internet and GPS systems were first developed in universities and national labs for military research, and then transferred to commercial businesses.

At the second growth stage, the new technology shows its market potential, private capital jumps in; market-share expands rapidly, newly issued stock prices soars. At this stage, market competition is the driving force of market expansion. However, safety and environmental standards, as well as financial regulations, are necessary for constructive competition. Herd behavior may appear in generating market instability, such as the case of the dot-com bubble in 2000.

At the third stage of market saturation, corporate profits fall and industrial concentration increases. Monopolistic competition may stiffen new innovations. Anti-trust laws are useful for preventing market concentration and market manipulation. We saw the industry concentration trends in the 2000's after liberalization in the 1980's in the U.S., including telecommunication, computer, software, airline, banking, and retail markets. The 2008 financial crisis was rooted in the American disease where financial oligarchs crowded out the real economy (Johnson 2009, Chen 2010).

The big challenge occurs at the fourth decline stage. Some sunset industries struggle for survival or end up in bankruptcy. Past investment turns into big loss. Stock prices drop and financing costs goes up. Decisions on a life-saving investment or a cut-loss strategy are life-or-death issues for old industries. Large-scale unemployment demands government assistance. Transition from a sunset industry to a sunrise industry needs coordinated efforts between the private and public sector. A typical example is the coal industry in Britain, which was the driving force of industrial revolution in the 18th century but declined in the 1980's. Industrial policy for encouraging new radical technology (still in an infant stage) and retraining displaced workers from obsolete technology may be useful. Conventional monetary policy and Keynesian fiscal policy are not enough for structural adjustment at this stage. Conflicts or wars more likely occur at this stage.

Similarly, institutional arrangements must adapt to different stages of technology life cycles. Clearly, the market force alone cannot insure a healthy economy since technology metabolism may generate substantial social instability and a strong impact to biodiversity. The transaction cost argument against regulation is misleading, since sustainability of an ecological system cannot be solely judged by minimizing entropy (waste heat or transaction costs) during industrialization (Chen 2007). The issue is not big vs. small government, but effective vs. incompetent government in dealing with complexity and stability of mixed economies. A selection mechanism in market regulation plays a central role in institutional evolution (Chen 2007).

4. Risk Attitude and Culture Diversity in Learning Strategy

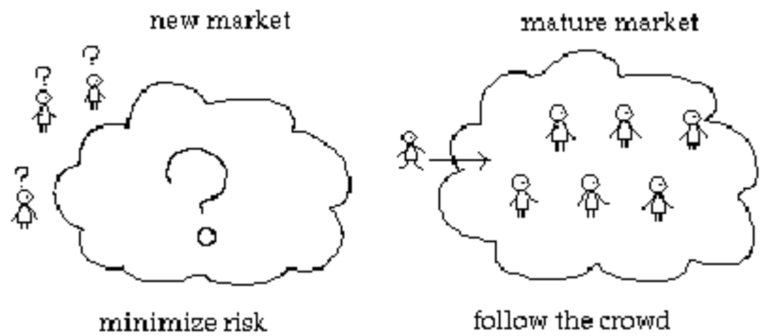
From Table 3, the resource-population ratio varies greatly between Asian and Western countries. We may characterize Western civilization as a labor-saving but a resource-consuming culture, while Asian and Chinese civilizations are resource-saving but labor-consuming cultures (Chen 1990, 2010). Technologically speaking, China had the capability to discover America before Columbus (Menzies 2002). Needham asked the question why did science and capitalism originate in the West, not in China (Needham 1954). The answer can be traced from the interaction between environment and culture in history (Chen 1990).

There is an intensive debate on altruism in economics (Simon 1993). It is difficult to distinguish altruistic from selfish behavior from empirical observation. However, we can easily measure the risk attitude between different cultures, such as risk aversion versus risk taking in facing an unknown market or opportunity.

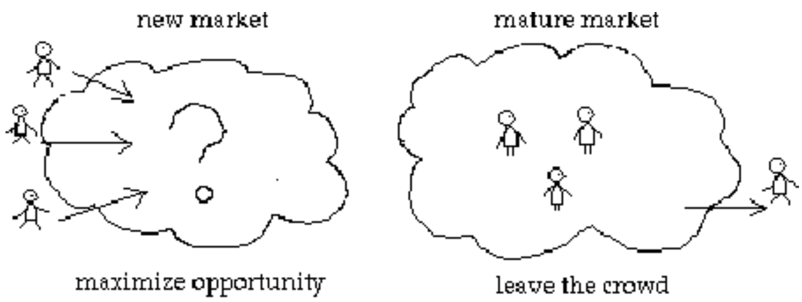
In neoclassical economics, economic risk is characterized by a static probability such as in the case of gambling; there is no uncertainty associated with a new market and a new technology in a strategic decision. In our dynamic competition model, we introduce a new kind of risk attitude in open economies: the risk of facing an unknown market or technology uncertainty. Both Knight (1921) and Keynes (1936) emphasized the role of uncertainty, which is different from risk in the sense of static statistics. Schumpeter's concept of the entrepreneurial spirit is critical in facing evolutionary uncertainty rather than static risk.

4.1 Learning by Imitating and Learning by Trying: Risk-Aversion and Risk-Taking Culture

The cultural factor plays an important role in decision-making and corporate strategy. There is a great variety in the degree of "individualism" between western and oriental cultures. Risk-aversion and risk-taking strategies differ when facing an emerging market or new technology (Fig. 8). Clearly, the strategy of learning by doing is not applicable for an open economy, since the accumulation process is only relevant for existing technology (Arrow 1962). In a new market, knowledge comes from learning by trying, which is a trial and error process from an evolutionary perspective (Chen 1987). The alternative strategy is learning by imitating or following the crowd. The risk-taking and risk-aversion attitudes in facing a new market or technology can be visualized in Fig. 4.



(a). Risk-aversion behavior.



(b). Risk-taking behavior.

Fig 4. Risk-aversion and risk-taking behavior in competition for market share and technology advancement.

From Fig. 4, different cultures have different rationales behind their risk attitudes. When facing an unknown market or unproved technology, risk-taking investors often take the lead and venture to maximize their opportunities, while risk-averting investors prefer to wait and follow the crowd to minimize their risk. A critical question is: Which corporate culture or market strategy can win or survive in a rapidly changing market? To answer this question, we need to integrate the culture factor into competition dynamics in Eq. (3).

In industrial economies, resource competition essentially is a learning competition in adopting new technology. For understanding the link between cultural diversity and resource variability, we may introduce a culture factor into species competition. The original logistic equation describes a risk-neutral behavior by assuming a constant exit rate. We introduce the behavioral parameter a by introducing a nonlinear exit rate as a function of the learner's population ratio (Chen 1987):

$$R(r, a, \frac{n}{N}) = r(1 - a\frac{n}{N}) \quad \text{Where } -1 < a < 1. \qquad (6)$$

Here, n is the number of users of this new technology.

We may consider the constant r as a measure of the learning difficulty when adopting a new technology, which means that the harder to learn, the faster the exit. We put the behavioral factor at the exit rate for mathematical simplicity, since the original exit rate is a linear term. The modified exit rate becomes a quadratic term, so that we still have an analytic solution for this nonlinear dynamical model. Otherwise, we can only do numerical simulations using mathematical modeling.

The 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. At the initial stage, few people dare to try a new market; the exit rate is the same for all people. However, when more and more people accept the new technology, business strategy becomes increasingly diversified. For risk aversion investors, their exit rate declines, since they feel deceasing risk. But risk-taking entrepreneurs are more likely to exit, since they feel decreasing opportunity. When varying a from minus one to plus one, we have a full spectrum of varying behavior, from the extreme risk-aversion conservatism to the extreme risk-taking adventurism. There are different meanings of conservatism between the West and the East. To avoid a conceptual misunderstanding, we will define risk-aversion behavior as a