

Research on Technological Innovation Evolution Based on Self-organization Theory: the Case of China Communication Industry

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Abstract—The technological innovation evolution is a self-organization process. There are complex characteristics in technological innovation system. From the perspective of system theory this paper illuminated the self-organization characteristics of technological innovation system and analyzes the self-organization mechanisms of the innovation process and characteristics of openness, dynamic, nonlinearity, fluctuation and indetermination and constructed the self-organization process model of technological innovation and diffusion then carried on the confirmation with statistical software to the model fitting degree and the model parameters, using the data of China communication market, obtained the quite satisfied result. These models have realized the integration of the natural sciences and the social sciences, and developed a new method for studying on the evolution and diffusion process of the technological innovation and diffusion.

Index Terms—technological innovation system, self-organization, evolution model, diffusion model

I. INTRODUCTION

Innovation is the source of the human wealth and the great driving force for economic development. President Hu Jintao pointed out explicitly that we must construct an innovation and creative country with Chinese characteristics. Facing the present global financial crisis, foothold enterprise oneself, improving the capability of independent innovation appears to be even more crucial. Two disparate routes can be taken to construct the technological innovation system, one is other-organization, and the other is a self-organization. The two forms' differences lies in the former shows the enterprise and the university are passive, the government is initiative; The latter appears the enterprise and the university is initiative, the government is auxiliary. At present, China's industry technological innovation is at the vigorous development stage. How to formulate and adjust cooperation mechanism according to the market

shift and the social development request, the self-organization theory has provided us with one kind of new ideas. The self-organization theory studies chiefly the formation and development of self-organization system. The important conditions of forming self-organization are the openness, non-linearity, non-equilibrium state and fluctuation of this system. To carry on the analysis of technological innovation system by using the self-organization theory has practical significance.

II. THE RELATED LITERATURE REVIEW

The primary meaning of system theory is about the thing integrity idea and concept with connection and development [1]. In 1890, Marshall, a famous economist, in "Principle of economics" proposed that we should use the system biology the evolution thought to study the economics. Since the 1980's, with establishment and the development of the self-organization theory, there has been the school of theory of evolution which study innovation economics by using self-organization theory. American scholars Nelson and Winter (1982) published a book named "theory of evolution of economic change", and laid the theory of evolution School foundation for innovative research [2]. Ziman (2000) published a book "as the evolutionary process of technological innovation," and further expounded the idea of evolution of technological innovation. From the self-organization point of view, technological innovation is the innovation system forms with the process which evolves to the order; therefore, we can through the inspection technological innovation system with the condition which evolves to the order direction to reveal regularity of the evolution of technological innovation [3]. Subsequently, a group of foreign scholars done a lot of research on regional and national innovation system by using the self-organization theory, industrial, and obtained the rich research results[4-9].

In recent years, some domestic scholars attempt to use the theory of system self-organization to study social science research questions. Qin shushing (2004) pointed out that technology innovation is a complex system. Autonomy is the inside spirit of self-organized evolution

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of technology innovation system. Good social environments are necessary outside terms of self-organized evolution of technology innovation system [10]. Ai Renzhi (2005) analyzed the internal mechanism for the development of urban commercial banks and then suggests through introducing the openness and external negative entropy to build up the urban commercial banks' self-organization functions by applying self-organization theory, a relatively new theory, that is key and critical factors for the development of an organization [11]. Mao Jianqi and Yang Haishan (2006) indicated that the emergence of technological innovation is due to the interaction of its underlying factors such as knowledge, information and intelligence, plus the co – evolutionary process of market, humanity, society, and social system. Tech-innovation owes its success to the selection of the market; on the contrary, the failure of tech-innovation is its failure to be selected by the market [12]. Luo Wenjun and Gu Baoyan (2006) revealed the micro-mechanism of knowledge innovation and process-condition to increase success possibility of knowledge innovation on the base of theory of self-organization, and hoped to have some help to entrepreneurs and managers in practice [13]. Fang Linyu and others indicated that as a complex system, the independent intellectual property growth of SMEs is not only dynamic but also self-organized. Through a detailed analysis on the processes, mechanism and characters of self-organization of SMEs' independent intellectual property growth, they endeavors to contribute to the growth rate and success probability of independent intellectual property of SMEs in China[14].

Looking at the above-mentioned studies we can find three aspects are insufficient. (1) In the research technique, they failed to get rid of the shackles of the traditional theoretical framework. (2) In the content system, research results are more scattered, lack of understanding to its complexity. (3) In the research angle, the quantitative analysis of technological innovation system evolution is insufficiency.

In view of the inadequacy of the existing literature, according to self-organization theory, based on the combination of industry economics and system dynamics

theory, this paper takes the evolution of the technology innovation system and product proliferation as the research object. Through the analysis of technological innovation system structure and characteristics of self-organization, we set up the evolution models of self-organizing innovation systems, and analyze them. At the same time, we also analyzed the diffusion model of innovative products and take communications industry as an example to carry on the empirical analysis.

III. THE SELF-ORGANIZATION CHARACTERISTICS OF TECHNOLOGICAL INNOVATION SYSTEM

Self-organization theory is the theory about phenomenon and the rule of self-organization. The self-organization theory is consists of several parts: I. Prigogine's Dissipative Structure Theory, H. Haken's Synergetics, Thom's Morphogenesis, M. Eigen's Hypercycle Theory, Mandelbrot's Fractal Theory and Lorenz's Chaotic Theory. The theory reveals the evolution process from the disorder to the orderly of system. The self-organization theory studies chiefly the formation and development of self-organization system. The important conditions of forming self-organization are the openness, non-linearity, non-equilibrium state and fluctuation of this system. To carry on the analysis of technological innovation system by using the self-organization theory has practical significance.

Mr. Qian Xuesen, systems engineering scientist, said that the system itself trend toward an orderly structure can be referred to as a self-organizing systems. Self-organizing system is an open system which is far away from balance. With the non-linear change of external environment and internal subsystem, the system unceasingly hierarchies and move toward the ordered state spontaneously from the disordered state. Openness, dynamic, nonlinearity, fluctuation and indetermination in system are the important conditions for the formation of self-organization [15-20]. Figure 1 clearly displays the self-organization structure of technological innovation system.

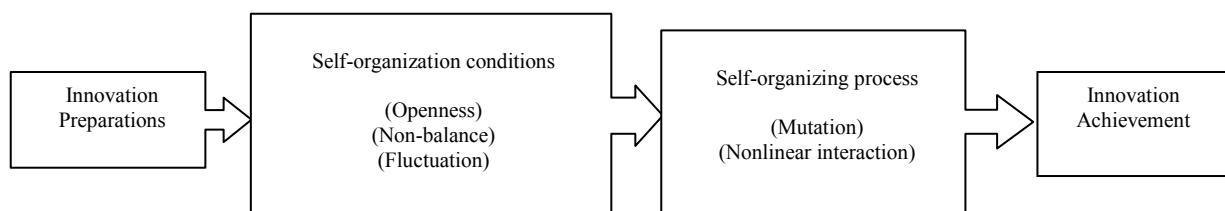


Figure 1. Self-organization structure of technological innovation system

According to the self-organizing systems theory the phenomenon of self-organization needs the necessary conditions: (1) openness (2) non-equilibrium state (3) non-linear (4) mutation (5) fluctuations (6) positive feedback.

The evolution of technological innovation system is the polymerization and superimposition process of many technological innovation processes, is the process of innovation and cluster development. G. Dosi, a British economist, divided the clustering evolution of self-organization of the innovation process into two stages,

namely the self-stabilization process and the self-restructuring process. Subsequently he proposed a "technological paradigm-technical orbital model". The

self-organization structure of technological innovation system is shown in Figure 2.

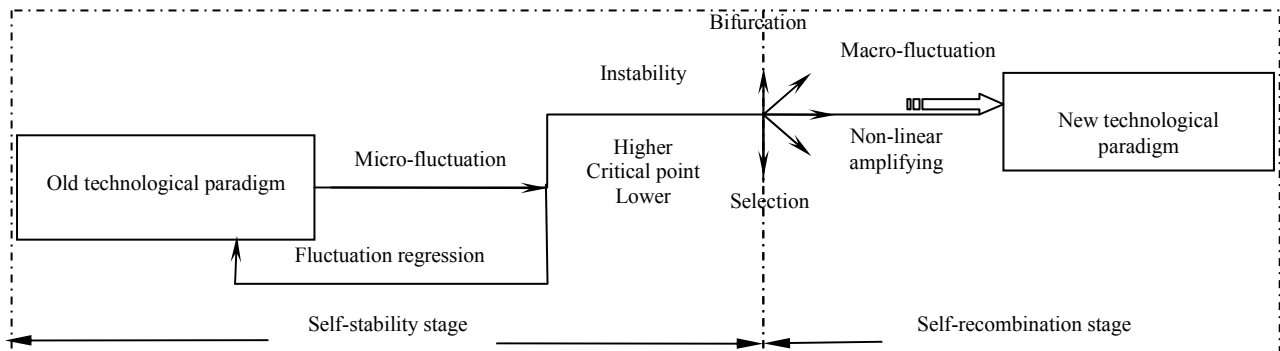


Figure 2. Self-organization evolution process of technological innovation system

IV. THE SELF-ORGANIZATION EVOLUTION MODEL OF TECHNOLOGICAL INNOVATION SYSTEM

A. The model of self-organization evolution

According to the mutation theory of Synergetics, the dynamic equation can be used to describe the evolution process of self-organizing system. [21, 22].

$$X = ax^2(1-x) - bx + \Gamma(t). \quad (1)$$

- x : Innovation maturity;
- a : Strength coefficient;
- b : Limit coefficient;
- $\Gamma(t)$: Random "fluctuation".

Assuming that:

$$q = \sqrt{ax} - \frac{\sqrt{a}}{3};$$

$$\alpha = \frac{a-3b}{3},$$

$$\beta = \frac{2a-9b}{27} \sqrt{a};$$

$$\Gamma'(t) = \sqrt{a}\Gamma(t)$$

We convert equation (1) into equation (2).

$$\frac{dq}{dt} = -q^3 + \alpha q + \beta + \Gamma'(t). \quad (2)$$

When $\beta = 0$, $\Gamma(t) = 0$ only consider a dynamic equation which contains the single parameter.

$$\frac{dq}{dt} = -q^3 + \alpha q. \quad (3)$$

B. Analysis of the evolution model

When $\frac{dq}{dt} = 0$, we can get three steady-state solutions.

There are $q_1 = 0$, $q_{2,3} = \pm\sqrt{\alpha}$. Thus, when $\alpha < 0$, $q_1 = 0$ is a steady-state solution of the system. In this case, $q_{2,3}$ are imaginary number and no practical significance. When $\alpha > 0$, three steady-state solutions are the real number solutions, at this point $q_1 = 0$ is the system's unstable steady-state solution, $q_{2,3} = \pm\sqrt{\alpha}$ are the stable steady-state solutions. Namely $\alpha = 0$ is the bifurcation point of system (3) and when α increases and surmounts this point from the negative value, the innovation system both has the creation of new stationary state lives and increase of stable state number, as well as the exchange of stability. Significant changes of the system qualitative nature indicated that business, by emphasizing innovation, encouraging knowledge-sharing, achieves a qualitative change in the overall and seek new development, which is orderly process of evolution from a loss of the old structural stability to the establishment of a new structure. The innovation process is non-linear, and its evolution path is impacted by $ax^2(1-x)$. Increasing the positive feedback coefficient a or reducing the damping coefficient b is the key to achieve a new self-organized structure. This is exactly the earlier analysis of necessary conditions and internal factors for the self-organization innovation [23].

The technological innovation evolution of China's communications industry is a good example. China begins to apply Wireless paging technology from 1990's. The number of wireless paging users increased from 440,000 in 1990 to 48,840,000 in 2000. However, at the end of the 20th century, the steady increasing state of wireless paging technology was broken, and personal communication technology innovation emerged a bifurcation point. A few years later, more advanced and convenient mobile communication products (mobile

phones, walkie-talkie, “little smart” (PHS)) fast grow, and wireless paging industry declines day after day. China's pager users have been very few. According to the statistical bulletin of Ministry of Industry and Information Technology, the number of wireless paging users was only left over 970,000 until December 2005, reduced 298% comparing to the end of last year. The Personal Handy-phone System product (little smart) rapid diffused since 2003, and the annual number of new PHS users are more than 20,000,000. In the past two years, mobile phone rates continued to drop, and one-way charging was implemented gradually. Nowadays men more like to choose cell phones as a tool for contact. Up to August 2008, the number of China's mobile phone users has surpassed 600,000,000 (616,017,000), which popular rate reached 45.6 percent. At the same time, along with the Internet technology's popularization, the communication has achieved a higher-level order steady progression condition in recent years.

V. THE SELF-ORGANIZATION DIFFUSION MODEL OF TECHNOLOGICAL INNOVATION SYSTEM

A. The model of self-organization diffusion

Assumption 1: The innovation technology and the product owner have certain controlling force to target market's user and the price. The diffusion process is the three combined actions of proliferation main body, the competitor and the supplementary enterprise;

Assumption 2: We do not consider the spread of the first purchase and repeat purchase about the innovation technologies and products, only to consider the market share eventually of technology and products;

Assumption 3: The innovation diffusion process conforms to the logistic principle, and there is a technological innovation ability limit or the market maximum capacity.

The self-organization evolution tracks of the technological innovation system can be described by the S-curve of the ecosystem self-organized growth [24, 25].

On the one hand, according to the Bass diffusion model principle, the following model can be used to describe the self-organization evolutionary process of technological innovation and diffusion system.

$$\frac{dN(t)}{dt} = p[M - N(t)] + q \frac{N(t)}{M} [M - N(t)]. \quad (4)$$

$N(t)$: Existing technological innovation ability or market share;

$\frac{dN(t)}{dt}$: Technological innovation change or the market share change;

M : Technological innovation limit or max market share;

p : Innovation coefficient or external-influence coefficient ($p > 0$);

q : Imitation coefficient or internal-influence coefficient ($q > 0$).

The first item of right side in the equation (4) represents the part which was influenced by the external-function, called Innovators; the second item represents the part which was influenced by the internal- function, called Innovators Imitators. The S curve indicated that the diffusion speed increases firstly, and then reduces, but the number of innovation users increases unceasingly, and achieves the saturated condition (M) finally.

Set up the system initial condition $N(0) = 0$. Separation the variable of the formula (4) and Take integrals to both sides. We can result in:

$$N(t) = M \left[\frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} \right]. \quad (5)$$

According to the equation (5) we can make the estimate and the forecast of the technological innovation diffusion.

On the other hand, according to the Logistic diffusion model principle, the following model can be used to describe the self-organization evolutionary process of technological innovation and diffusion system.

$$\begin{cases} \frac{dN_{(t)}}{dt} = rN_{(t)} \left(\frac{M - N_{(t)}}{M} \right) \\ N|_{t=0} = N_0 \end{cases} \quad (6)$$

$N_{(t)}$: Existing technological innovation ability or market share;

$\frac{dN(t)}{dt}$: Technological innovation change or the market share change;

M : Technological innovation limit or max market share;

r : Natural growth rate or diffusion rate of technological innovation.

The first item of right side in the equation (6) represents the part which was influenced by the external-function, called Innovators; the second item represents the part which was influenced by the internal- function, called Innovators Imitators. The S curve indicated that the diffusion speed increases firstly, and then reduces, but the number of innovation users increases unceasingly, and achieves the saturated condition (M) finally.

Now, we will adopt Logistic diffusion model to study the issue.

B. Analysis of the diffusion model

In the diffusion model (6), $(M - N_{(t)}) / M$ represents the surplus innovation resources in system and it may supply to the population for the use of its sustainable growth.

(1) When $N_{(t)}$ is much smaller than M , $(M - N_{(t)}) / M$ is close to 1. The equation is

$dN_{(t)} / dt = rN_{(t)}$ and the innovation system assumes exponential growth. The innovation population growth potential is at the largest condition.

(2) When $N_{(t)}$ is near to M , $(M - N_{(t)}) / M$ is close to 0. This means that almost all the innovation resources are used and the potential of innovation system growth no longer exists. Figure 3 and figure 4, respectively, demonstrate the evolution and growth rate curve of technological innovation system. The time points t_1 and t_2 express the peak of growth speed and innovation ability (or call market absorption capacity) separately.

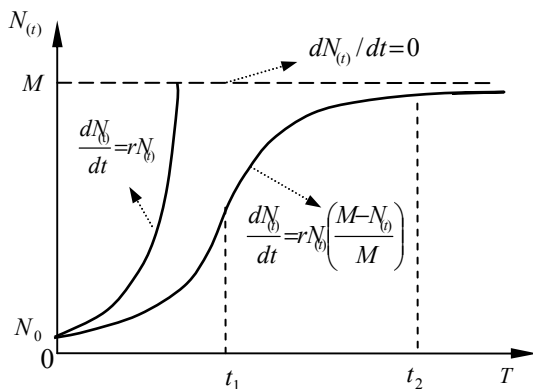


Figure 3. The growth curve of technological innovation system

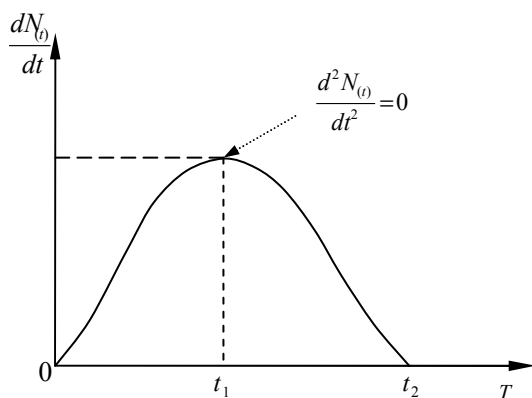


Figure 4. The growth rate curve of technological innovation system

Separating the variable of the formula (6), we can get:

$$\left(\frac{1}{N_{(t)}} + \frac{1}{M - N_{(t)}} \right) dN_{(t)} = r dt \cdot \quad (7)$$

Taking integration to both sides of formula (7), we can result in:

$$N_{(t)} = \frac{M}{1 + C e^{-rt}} \cdot \quad (8)$$

In the formula C is the integral constant coefficient, and its value is decided by extreme value M and system

initial condition $N_{(0)}$. According to the initial conditions: $N_{(0)} = N_0$, it may result in: $C = (M - N_{(0)}) / N_{(0)}$.

Therefore, the solution of formula (6) to meet the initial conditions is the next formula:

$$N_{(t)} = \frac{M}{1 + \left(\frac{M}{N_0} - 1 \right) e^{-rt}} \cdot \quad (9)$$

According to the equation (9) we can make the estimate and the forecast of the technological innovation diffusion [26].

VI. EMPIRICAL STUDY

A. Data selection

China communications industry has achieved rapid development over the past 10 years. The fixed phone users increased year by year, up to the end of 2007, the number of users has surpassed 350,000,000. The Chinese mobile network experienced the transformation from the analog network to the digital network. Mobile phone users have grown very rapidly, and the number of users has broken through 600,000,000. Chinese internet experienced the connection patterns transformation from dial-up to ADSL, and the current number of users has surpassed 350,000,000. The Chinese mobile network come through the analog network to the digital network transformation, the number of mobile network users grew extremely. Especially mobile network users developed rapidly near ten year, and the network user number already surpassed 600 million. China became having most mobile subscribers number in the world. This has cultivated the giant market for the 3G network, therefore the people paid more attention to rapidly promote China 3G network extremely.

Statistical data coming from the websites of China Internet Network Information center and Ministry of Industry and Information Technology of the People's Republic of China. The accumulation subscriber amount of the fixed phone, mobile phone and internet each year from 1991~2007 were shown in Table 1.

B. Estimate and examination

Regarding the non-linear regression model, we must consider not only how to determine its concrete form according to the question nature and the union actual sample material which we study, but also must consider how to the parameter estimate in the model [27]-[29]. The non-linear regression model most commonly used method still was least squares method, but which needs to make the suitable transformation according to the model different type. Through the SPSS15.0's non-linear regression functions we estimate parameters showed in figure 2, and the results of the estimated parameters are in Table 2.

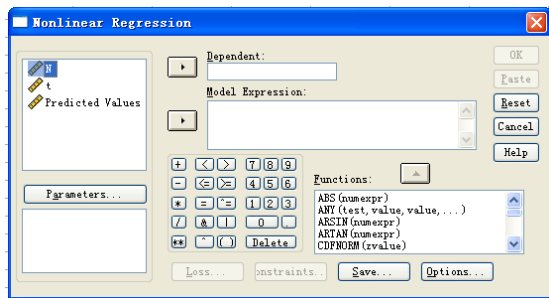


Figure 5. The non-linear regression functions of SPSS15.0

According to the parameter estimated may obtain the popularizing mode of the total users showed in equation (10) to (12).

$N_1(t)$: Accumulation amount of fixed phone users;
 $N_2(t)$: Accumulation amount of mobile phone users;
 $N_3(t)$: Accumulation amount of internet network users.

$$N_1(t) = 43787.344 \left[\frac{1 - e^{-0.317t}}{1 + 42.787e^{-0.317t}} \right]. \quad (10)$$

$$N_2(t) = 81314.597 \left[\frac{1 - e^{-0.399t}}{1 + 405.573e^{-0.399t}} \right]. \quad (11)$$

$$N_3(t) = 81705.465 \left[\frac{1 - e^{-0.329t}}{1 + 115.722e^{-0.329t}} \right]. \quad (12)$$

TABLE I.
THE ACCUMULATION AMOUNT OF CHINA COMMUNICATION USERS EACH YEAR (UNIT: TEN THOUSAND)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999
SN	1	2	3	4	5	6	7	8	9
Fixed phone	849.8	1264.6	1796.9	2886.3	4070.6	5494.7	7031	8742	10871.6
Mobile phone	4.7	17.7	63.8	166.8	362.9	685.3	1323.3	2385.9	4330.3
Internet network	/	/	/	/	/	/	64	210	890
Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
SN	10	11	12	13	14	15	16	17	18
Fixed phone	14482.9	18036.8	21441.9	26330.5	31244.3	35043.3	36781.2	36544.8	34080.4
Mobile phone	8453.3	14522.2	20661.6	26869.3	33482.4	39342.8	46108.2	54728.6	64123.0
Internet network	2250	3370	5910	7950	9400	11100	13700	21000	25300

TABLE II.
THE PARAMETER ESTIMATES

Parameters User categories	M	r	R squared
Fixed phone	43787.344	0.317	0.985
Mobile phone	81314.597	0.399	0.995
Internet network	81705.465	0.329	0.985

According to the above models, we can make the fitting curve figures, such as Fig.5 to Fig.7. As we can see from the figures, the diffusion of fixed telephone and mobile phone has entered a stable growth stage, and the results fit very well, The Internet network is still in the early stage of development, and the rate of diffusion is not stable. Its fitting result is not precise enough than the above two, but still reflects the basic trend of diffusion.

Through above analyses, we can legibly be aware that China communication market is not unsaturated; there are capacious markets to develop. After China entering WTO, communication market opening is the certainty of economic globalization. China telecom service industry once offered a great market for the development of Chinese communication manufacturing industry. However because it is not long for China carry out market economy and there has a lot to learn about

competition rules or theory to Chinese communication industry.

Difference from other infrastructure pattern, communication industry can sustain the nature of spontaneous monopoly because of its characters in some sense. Compared with electric power, communication networks can penetrate to the society more rapidly. In traditional industry, the production cost per unit will increase with output under the restriction of resource and energy. So the value will decrease for a consumer with increasing quantity of every material goods, which is the principle of decreased marginal efficacy. In communication industry the cost will decrease with the increase of quantity, for there are less restriction of resource and energy. So the more the information, the more the utility the consumer will possess, which is the principle of increased marginal efficacy, the logical result

of monopoly. On the other hand, monopoly will result in internal inefficiency and bureaucratize, which undermines the efficacy brought by market. communication company operate in standard principle of corporation rather than infrastructure or public products.

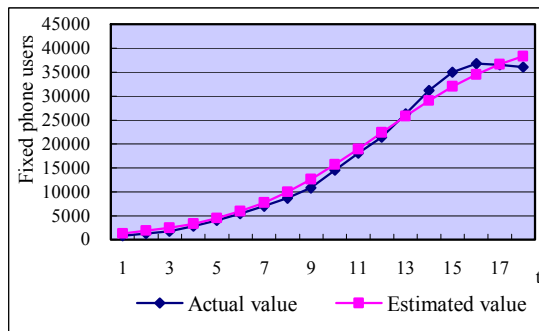


Figure 6. Model fitting curve of fixed phone diffusion

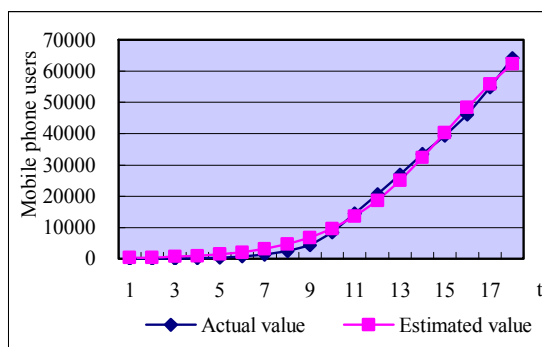


Figure 7. Model fitting curve of mobile phone diffusion

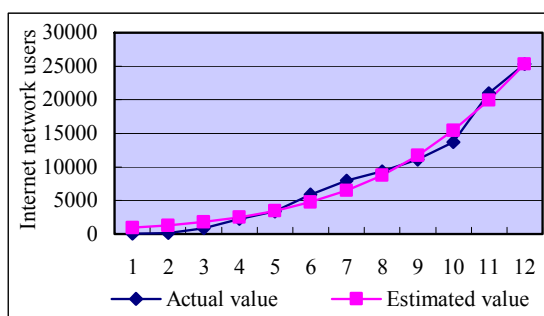


Figure 8. Model fitting curve of internet diffusion

VII. CONCLUSIONS AND FUTURE WORK

By means of the self-organization theory which includes Dissipative Structure, Synergetic, Morphogenesis, Hyper cycle Theory, Fractal Theory and Chaotic Theory and combining with the Bass diffusion model principle, we analyzes the self-organization mechanisms of the innovation process and characteristics of instability, the multiplicity (branch), the sudden change

and stochastic “the fluctuation” and constructs the self-organization model of technological innovation, then carries on the confirmation with statistical software to the model fitting degree and the model parameters, using the data of China communication market, obtains the quite satisfied result. This model has realized the integration of the natural sciences and the social sciences, and has more in-dept understanding about the achieve mechanism and the evolutionary process of the technological innovation and diffusion.

It can be seen from the research that studying on the questions of technological innovation system evolution from the system and evolution view conforms to the technological innovation process dynamic and the complexity, and it realizes a stable crosswise union between the natural sciences and the economic science. this develops a new mentality for researching on the technological innovation and diffusion.

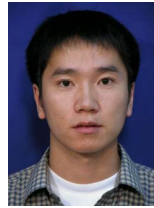
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