Research on the Synergy Degree of China Yangtze River Delta Region Technology Innovation System Evolution from the Perspective of Technology Innovation Chain

Xu Binfeng[1], Song Wei, Ph.D[2]

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ABSTRACT

This paper divides technology innovation system into research and development input subsystem, technology research and development subsystem and technology application subsystem from the perspective of technology innovation chain, combining with the system theory. Then selects the corresponding ordinal variables, makes an empirical analysis of the synergy degree of Yangtze River delta regional technology innovation system evolution of complex system synergy degree model which based on the data on 2002-2009. The results show that the development of synergy degree of the technology innovation system appears a rising trend and the technology application subsystem is the key factor of direction and degree of synergy development in the evolution process of regional technology innovation system in the Yangtze River Delta of China. Finally, this paper analyzes the characteristics and causes of synergy degree's evolution, and puts forward the corresponding policy recommendations to different problems.

1. Introduction

In the globalization wave, the competition between the areas is not only the competition of economic power, but also the competition of regional technology innovation ability (Lundavall & Borrass, 1997). The science and technology innovation ability of the regional innovation system become one of the most important factors of regional to achieve competitive advantage. From the perspective of system theory, the regional technology innovation system has complex structure and multiple functions (Cooke & Morgan, 1994). It is constituted by many subsystems, whose coordinated development of subsystems is the basis to realize regional technology innovation system's total function. Regional technical innovation ability is the output variables of regional technology innovation system, which directly decides the exertion of overall function of the system. Technology transfer subsystem has always been a weak link in regional technology innovation system in China. Therefore, it is necessary to study the synergy degree of regional technology innovation system from the perspective of the system.

2. Current Status of the Study

The research on regional innovation system in the world is mainly focused on the theoretical research and empirical analysis. In the field of the regional innovation system theory, scholars have already carried on the exploration and research in the aspects of connotation, structure, operation mode, environment of the regional innovation system. In the empirical research area, most of the scholars conduct their research on the efficiency of regional innovation system and the measurement of regional innovation ability. The measurement and analysis of synergy degree is a new hotspot in the empirical analysis field of regional innovation.

Cooke (2002) analyzed the operation mechanism of regional innovation system based on the empirical research, and points out that the network of infrastructures, which support innovation constitutes the regional knowledge production and diffusion subsystem. Guan Jiancheng and He Yin (2005) used DEA method to evaluate China's regional innovation activities of technical effectiveness, economic effectiveness and the comprehensive effectiveness. Liu Fengchao, Pan Xiongfeng & Shi Dingguo (2006) used principal

[1] School of Public Affairs, University of Science and Technology of China, E-mail: 215619002@qq.com'
[2] Professor, School of Public Affairs, University of Science and Technology of China, E-mail: st-michel@163.com

component analysis (PCA) to evaluate the comprehensive development of economy and S&T system in Liaoning province in 1995-2022 based on the coordinated development index system of economy and S&T. Then, they made a quantitative analysis on the harmonious development of economy and S&T of Liaoing province by regressive analysis and harmonious degree calculation. Yin Linsen (2010) built complex system synergy degree model and coordinated development trend model from the static and dynamic angle, used the data of science and technology system and economic system of Shanghai in 1997-2006 to make an empirical research and summarized the coordinated development degree between science & technology and economic of Shanghai. Zheng Guanghua (2010) made a quantitative evaluation which is based on the system coordination theory for the coordinated development degree of Henan province's regional innovation system from the following aspects: the subsystem of innovation environment, the subsystem of innovation main body and the subsystem of innovation resources.

From the above, the content of existing research results has an important enlightenment function for this paper, and there also have some space to go on study: (1). The research conclusions were incompletely consistent with each other due to the differences in research method and index system; (2). There is no scholar uses synergy degree model to research the synergy degree among research and development input subsystem, technology research and development subsystem and technology application subsystem from the perspective of the development level of three internal subsystems of regional innovation system in China.

Based on this situation, the research logic and methods of this paper are as follows: Firstly, divide technical innovation system into research and development input subsystem, technology research and development subsystem and technology application subsystem from the perspective of technology innovation chain and system theory. Secondly, make an empirical analysis to the synergy degree of Yangtze River delta regional technology innovation system's evolution by complex system synergy degree model. Finally, combine the results of empirical analysis to put forward the corresponding policy recommendations to the coordinated development of the technology innovation system in Yangtze River delta region of China.

3. The Research for Evolution of Regional Technology Innovation System and Synergy Degree

3.1 The Definition for the Coordination of Regional Technology Innovation System

Coordination means the process that under the management activities of system internal self-organization and external regulation, each internal organizations of subsystem and subsystems are harmonious coexistence, so as to realize the total effect of the system. The consistent degree among systems or system components in the process of evolution is known as the synergy degree.

According to the opinion of synergetic, the orderly development of system elements and coordinated development among elements are the basic condition of the total function of system. They also determine the internal order and structure of the system when they system reaches the critical state. Academic researchers are generally based on a specific purpose to carry on the corresponding research, for example, the scholars who research innovation system carry on their research from the following aspects: the input and output efficiency of system, the resources allocation of system, the coordinated development of system. These studies play the role of bridges for us to deeply understand technology innovation system. However, if these studies neglect the coordination characteristics of technology innovation system, we will not realize the importance of coordinated development of technology innovation system. In addition, academic circles have not reached a consensus on the definition and structure of the division of technology innovation system, which causes flourishing in technology innovation system research. Due to the lack of unified theoretical framework, the related research conclusions lack comparability. Therefore, this paper defines the concept and the structural division of technological innovation system according to prudent principle, and uses the coordinated degree model of the Yangtze River delta region technology innovation system to carry out empirical research on synergy degree.

The regional technology innovation system is a whole combined with research and development input subsystem, technology research and development subsystem and technology application subsystem. There are promoting effect and restrictive effect among the subsystems (Guo, Zhang & Sun, 2011). The change of the state of subsystems and state between subsystems codetermine the evolution trend of the regional technology innovation system, the development of the subsystems and coordinated development among the subsystems are beneficial to the optimization and upgrade of the system. The discordance of the three

subsystems of the technology innovation system will not only lead to structural imbalances between the three subsystems, but also cause a result that technological innovation system cannot exert the overall function (Bi, 2011). The discordance of the three subsystems is the fundamental reason of why the function of China's technology innovation system is weak. It shows that the innovative ability of regional technology innovation system depends not only on the influence of innovation resources, but also restricted by structural factors in the system. Specifically, the synergy degree of research and development input ability, technology research and development ability, technology application ability and upgrade ability affect the normal function of regional technology innovation system (Chen, Feng, Kang & Tian, 2011). Because of the insufficient investment and the unbalanced regional science and technology resources input in China cannot be solved in a short time, improve the synergy degree among three subsystems is the only way to promote regional technological innovation ability, and realize the regional innovation development.

3.2 The Construction of Evaluation Index System

Regional innovation system is divided into three subsystems: research and development input subsystem, technology research and development subsystem and technology application subsystem. In the research and development input subsystem and technology research and development subsystem, innovation resources such as capital, human resources are invested to produce innovation results like patent, paper, software (Yu & Guo, 2012). But not all of the innovation results are able to be industrialization, only through the application of science and technology investment, the new technology results can realize their economic value. The specific input and output process are as follows:

system	subsystem	ordinal variable	unit
technology innovation system	research and development input subsystem	R&D expenditure	100 million yuan
		R&D scientist and engineer	person
	technology research and development subsystem	trading of technology market	10,000 yuan
		Chinese invention patent application	item
		Chinese invention patent authorization	item
	technology application subsystem	sales revenue of new products	10,000 yuan
		energy consumption per unit GDP	ton of SCE/10,000 yuan
		GDP per capita (permanent resident population)	yuan/person

R&D: Research and Development, GDP: Gross Domestic Product, SCE: Standard Coal Equivalent.

Many indicators can measure the input and output of science and technology. This paper with reference to previous research literature, selected indicators based on the principles of science, representativeness, practicability and hierarchy, built the evaluation index system for regional technology innovation system and the development level of three subsystems from the view of input and output. The indexes of research and development input subsystem are R&D expenditure (100 million yuan) and R&D scientist and engineer (person). The indexes of technology research and development subsystem are trading of technology market (10,000 yuan), Chinese invention patent application (item) and Chinese invention patent authorization (item). The indexes of technology application subsystem are sales revenue of new products (10,000 yuan), energy consumption per unit GDP (ton of SCE/10,000 yuan) and GDP per capita (yuan/person).

3.3 Data Source and Collection

Science and technology innovation system has certain time lag. According to the experience of research in former literature, the data that has been collected and processed in this paper respectively come from the year t, the year t+1, the year t+2 for science and technology input, science and technology output and innovation output. The research object is China's Yangtze River delta regional technology innovation system

of Shanghai city, Jiangsu province and Zhejiang province. The research data mainly came from 《China Statistical Yearbook（2002-2012）》,《Shanghai Statistical Yearbook（2002-2012）,《Jiangsu Statistical Yearbook（2002-2012）》 and 《Zhejiang Statistical Yearbook（2002-2012）》.

4. Model Building and Data Processing

4.1 Model Building

The development process of technology innovation system is the interaction process among technology innovation subsystems. Its essence is a self-organization process to realize the technology innovation system from unrelated to related, from disorder to order, from low level to high level. The order degree and synergy degree of subsystems play an important role for the development speed of system in the process. The higher order degree with higher synergy degree of subsystems will be beneficial to the optimization and upgrading of technology innovation system (Liu & Tan, 2012). This article uses complex system synergy degree model to make empirical analysis for synergy degree of each subsystem in the evolution process of technology innovation system of China's Yangtze River delta region.

System internal variables are divided into slow relaxation variables and fast relaxation variables by synergy theory. The slow relaxation variable (order parameter) is the fundamental variables which decide the process and the characteristics of system evolution. The synergistic effect among the slow relaxation variables (order parameter) decides the trend of evolution process of system, which is from disorder to order. Therefore, to study the equation of a few slow relaxation variables of technology innovation subsystems, we can confirm coordinated development path of technological innovation system evolution.

The specific model building process is as follows:

Let the subsystem of technological innovation system be S_i, taking i=1, 2, 3. Assume that the order parameter in the development process of system Xi=（X_{i1}, X_{i2}, ... X_{in},）, n≥1, 1≤j≤n, j∈Z. If the value of X_{i1}, X_{i2}, ..., X_{in} is smaller, then the order degree of the subsystem is lower, on the contrary, the value is larger, the order degree of the subsystem is higher. The calculation formula of the order degree of subsystem's order variable is:

$$U_i(e_{ij}) = \begin{cases} \dfrac{e_{ij} - \min_{ij}}{\max_{ij} - \min_{ij}}, \text{ the variable j is positive indicator of subsystem i} \\ \dfrac{\max_{ij} - e_{ij}}{\max_{ij} - \min_{ij}}, \text{ the variable j is inverse indicator of subsystem i} \end{cases} \quad (1)$$

Where, $\max_{ij}$ and $\min_{ij}$ respectively are the maximum value and minimum value of the index j of the system i. From the formula (1), we can know that the smaller the value of $U_i(e_{ij})$, the smaller the effect of order degree of corresponding component to subsystem. On the contrary, if the value of $U_i(e_{ij})$ is larger, the effect of order degree of corresponding component of subsystems will also be larger.

The calculation formula of order degree of subsystem is as following:

$$U_i(e_j) = \sqrt[n]{\prod_{j=1}^{n} U_i(e_{ij})}, \text{ i=1, 2, 3} \quad (2)$$

From formula (2), we can know the value of $U_i(e_j)$ is smaller, the order degree of subsystem will be lower. On the contrary, the value of $U_i(e_j)$ is larger, the order degree of subsystem will be higher.

Suppose the order degree of each subsystem is $U_i^0(e_i)$ in the initial phase, when the technology innovation system develops to the time T_1, the order degree of each subsystem is $U_i^1(e_i)$. The calculation formula of synergy degree of the technology innovation system is:

$$S = \beta \sqrt[3]{\prod_{i=1}^{3}\left[U_i(e_i) - U_i^0(e_i)\right]} \quad (3)$$

where : $\beta = \dfrac{\min\left[U_i^1(e_i) - U_i^0(e_i)\right]}{\left|\min\left[U_i^1(e_i) - U_i^0(e_i)\right]\right|}$

In the formula (3), S∈[-1,1], if the value of S is smaller, the synergy degree of technology innovation system will be lower. On the contrary, if the value of S is larger, the synergy degree of technology innovation system will be higher. Otherwise, the synergy degree of technology innovation system is decide by the order degree of subsystems itself and the synergy degree among the subsystems, if one subsystem's degree of order is low, and another subsystem's degree of order is not high enough, the synergy degree of the entire technology innovation system will not be high.

4.2 The Empirical Result Analysis

We have analyzed the science and technology statistical data of China's Yangtze River delta region (two provinces and one city) in this paper, and measured the synergy degree of technology innovation system of each province and city in China's Yangtze River delta region in 2002-2009. See table 1, table 2 and table 3.

Table 1 The order degree of technology innovation subsystems and synergy degree of technology innovation system of Shanghai city

Shanghai	order degree of R&D input subsystem	order degree of technology R&D subsystem	order degree of technology application subsystem	synergy degree
2002	0.0655	0.0383	0.0471	
2003	0.0855	0.0833	0.1384	0.0435
2004	0.102	0.191	0.344	0.118
2005	0.339	0.295	0.492	0.315
2006	0.527	0.453	0.593	0.471
2007	0.762	0.613	0.728	0.648
2008	0.827	0.742	0.826	0.748
2009	0.951	0.947	0.956	0.901

Table 2 The order degree of technology innovation subsystem and synergy degree of technology innovation system of Jiangsu province

Jiangsu	order degree of R&D input subsystem	order degree of technology R&D subsystem	order degree of technology application subsystem	synergy degree
2002	0.0342	0.0387	0.0668	
2003	0.106	0.116	0.142	0.0747
2004	0.108	0.208	0.263	0.135
2005	0.245	0.420	0.185	0.212
2006	0.327	0.333	0.401	0.306
2007	0.491	0.492	0.594	0.478
2008	0.731	0.672	0.797	0.686
2009	0.943	0.948	0.950	0.901

Table 3 The order degree of technology innovation subsystem and synergy degree of technology innovation system of Zhejiang province

Zhejiang	order degree of R&D input subsystem	order degree of technology R&D subsystem	order degree of technology application subsystem	synergy degree
2002	0.0432	0.041	0.0467	
2003	0.116	0.160	0.171	0.103
2004	0.242	0.296	0.330	0.243
2005	0.382	0.146	0.419	0.236
2006	0.537	0.238	0.562	0.369
2007	0.687	0.458	0.737	0.570
2008	0.879	0.792	0.884	0.806

R&D: research and development. All table value in percent.

According to table 1, table 2 and table 3, we can summarize the synergy degree trend of the total technology innovation system and the specific conditions of the subsystems' synergy degree of Shanghai city, Jiangsu province and Zhejiang province in 2002-2009. Table 1 shows that the synergy degree of the technology innovation system of Yangtze River Delta region appears a rising trend in 2002-2009, particularly in 2008, the synergy degree of Shanghai city, Jiangsu province and Zhejiang province had a significant promotion. Specifically, the policy and regulation performance of Shanghai city and Jiangsu province which related to promote the R&D investment, technology transform and technology application was better. It led the order degree of three subsystems had a balanced increase, the synergy degree of the subsystems of the technological innovation shows a quickly rising trend, so as to achieve a good level. This is also the root cause that the science and technology policy performance of Shanghai City and Jiangsu province are leading in China. The technology innovation policy performance of Zhejiang province also shows a rising trend, but compared with Shanghai city and Jiangsu province, it has smaller change and slower rising speed. The order degree's rising range of technology research and development subsystem is lower than the order degree's rising range of research and development input subsystem and technology application subsystem. The main reason is that the patent license number is low, technology trading market is not active in Zhejiang province, it also indicates that the science and technology policy of Zhejiang province is more focused on the aspects of promoting technology innovation application and resource optimizing configuration, technology application became the main power to promote the performance of science and technology policy, the pattern of economic development of Zhejiang province is shifting from epitaxial type to intension type.

We can know the synergy degree's rising of technological innovation in China's Yangtze River delta regional mainly because of technology application rather than technology research and development. There are many different characteristics: synergy degree of the subsystems of technological innovation, which related to Shanghai City and Jiangsu province showed a rising trend in 2002-2009, and realized a good level in 2009, the synergy degree of the technological innovation system, which related to Zhejiang province also showed an increase trend as a whole in 2002-2009, but the order degree of technology research and development subsystem was lower than research and development input subsystem and technology application subsystem, this situation affected the total synergy degree's rising of the technology innovation system, and led the synergy degree of Zhejiang province was lower than Shanghai City and Jiangsu province. As three main body of China's Yangtze River delta region, different characteristics of the performance of the regional technology innovation policy could reflect the different characteristics of science and technology policy. Technology policy in Jiangsu province and Shanghai City focused on the input, development and application of technology innovation, it means Shanghai city and Jiangsu province pay great attention to the balance of development, optimize the allocation of science and technology resources. Comparatively speaking, Zhejiang province pays more attention to the technology application, and promotes technological progress.

5. Conclusions and Suggestions

This paper uses complex system synergy degree research method to make an empirical analysis for China's Yangtze River Delta region's evolution and development of synergy degree of technology innovation system in 2002-2009 from the perspective of technology innovation chain, enriches the research of synergy degree about the technology innovation system. This article emphasizes that the coordinated development of the

subsystems of the technological innovation is the key factor of the total function of the composite system. Each subsystem in order condition is the prerequisite for the efficient operation of technological innovation system. The study result shows that: (1) as time goes on, the order degree of technology innovation subsystem and synergy degree of technology innovation system about Shanghai city, Jiangsu province and Zhejiang province became increasingly higher in 2002-2009, the order degree of technology innovation subsystem of Jiangsu province was the highest among the three areas, this situation matched the innovation capability of Jiangsu province is the top in China, and proved that the promotion of the order degree of technology research and development subsystem and the synergy degree of the technological innovation system have great effect on innovation capability. (2) Similar to the cask theory of management, the subsystem which has the smallest order degree has the largest influence on the synergy degree of technology innovation system. That is to say, the weakest part restrict the fully function of the whole. Therefore, in order to improve the synergy degree of technology innovation system, we must try to improve degree of order in the lowest subsystem. In this case, this paper put forward the following countermeasures:

(1) Shanghai should try to improve the order degree of research and development input subsystem and technology research and development subsystem, support the construction of world-class engineering research center, increase the support of talent policy to absorb a number of research scientists and engineers engaged into the research center. Shanghai also should try to formulate fiscal, financial, tax incentive policy and measure to encourage development of technology consulting, service, transformation industry, gain more patent license, develop more large-scale technology trading market and realize more transformation of scientific and technological achievements.

(2) Jiangsu province should try to improve the order degree of technology application subsystem. In recent years, Jiangsu province has put a lot of manpower and material resources into the aspects of research and development input and technology research and development. It led the order degree of research and development input subsystem and technology research and development subsystem had a great improvement. Besides, R&D expenditure, the number of scientists and engineers, and patent number are more than shanghai. Also, the synergy degree of technological innovation system is greatly improved. But the order degree of technology application subsystem still cannot meet Shanghai's order degree of technology application subsystem. Therefore, Jiangsu province should strengthen the support of technology application to digest and absorb the dividends from technology research and development, increase investment in the early industrialization stage of technological achievements, set up industry funds, give priority to the advanced technology which is applicable to accomplish industrialization, and introduce private capital invest emerging industries.

(3) Zhejiang province should try to improve the order degree of research and development input subsystem and technology research and development subsystem. Strengthen the support of production-study-research cooperation mode, promote the depth of cooperative innovation among universities, scientific research institution and enterprise, clear property rights in the project initiation phase, provide better intermediary services in the technology development phase, clear transformation mode and interests distribution pattern in technology application phase to promote the transfer and transformation of science and technology achievements which come from universities and research institutions, encourage universities, scientific research institutions and enterprises to carry out joint training of talents, and support universities and research institutions to cultivate "targeted" professional high-tech talent. On the other hand, Zhejiang province should develop technology market, enhance support for the construction of the technology and information market, in order to let the enterprise cloud acquire the services of technology trade pricing, transfer, upgrading and cooperation, add the development of technology market into the provincial science and technology plan to let the government play a more important role in the development of technology trading market.

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