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Evaluation on the network of the national innovation systems in china from the perspective of knowledge network

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ABSTRACT

Scholars have successively studied the national innovation system from the perspective of system, perspective of knowledge flows and triple helix Angle and so on. This paper decomposes national innovation system into three networks from the perspective of knowledge network: scientific research network, technology development network and technology diffusion network, and evaluates the index system of national innovation systems networked based on the three secondary index of the network. This paper also puts forward the concept and measuring method of network group tightness and diversity, and evaluates the level of the network of China's national innovation system using principal component analysis. The evaluation results show that for more than 10 years the relation between the main behavioral bodies of the national innovation system has been getting closer, and the level of specialized division of labor and collaboration in innovation has been getting higher. At the same time, the low weight of papers of industry-university-institute cooperation and patent cooperation intensity tends to decline in recent years.

KEYWORDS

Index system of the network of national innovation systems;
Tightness of production-study-research cooperation network group;
Diversity.

INTRODUCTION

The fifth innovation model and the networking perspective of assessment of national innovation system

National innovation system was put forward in 1980s[1] by Lundvall, Freeman, Nelson, etc, which emphasized the interaction among government, companies, colleges, research institutes and intermediaries seeking for a series of social and economic goals in common[2]. It was a system in which innovation played the key role of revolution and development[3] and it could also promote the production, transfer, dissemination and application efficiently[4]. Chinese scholar Duan Fang-fang, Wu Tian-zu[5]

Pointed out when they studied the operation mechanism of national innovation system that national innovation system was a networking system which was composed of organizations and institutions. No functions of systems can work without other ingredients' functions and their coupling. In national innovation system, the process of interaction among all social parts is just the one of the operation of national innovation system, and effects of the interaction among elements directly determine the operation efficiency of the system. Efficient market mechanism, sufficient information flows and supporting systems of sound intermediaries and service guarantee the interaction and operation efficiency.

In order to analyze the different parts of national innovation system, 224 records (theses and book reviews) can be retrieved in Web of Science with "national innovation system" as the theme by the year of 2011. The networking figure of keywords of national innovation system can be plotted by citespace according to the 224 records as is shown in figure 1, in which there are mainly six clusters labeled with red dotted circles.

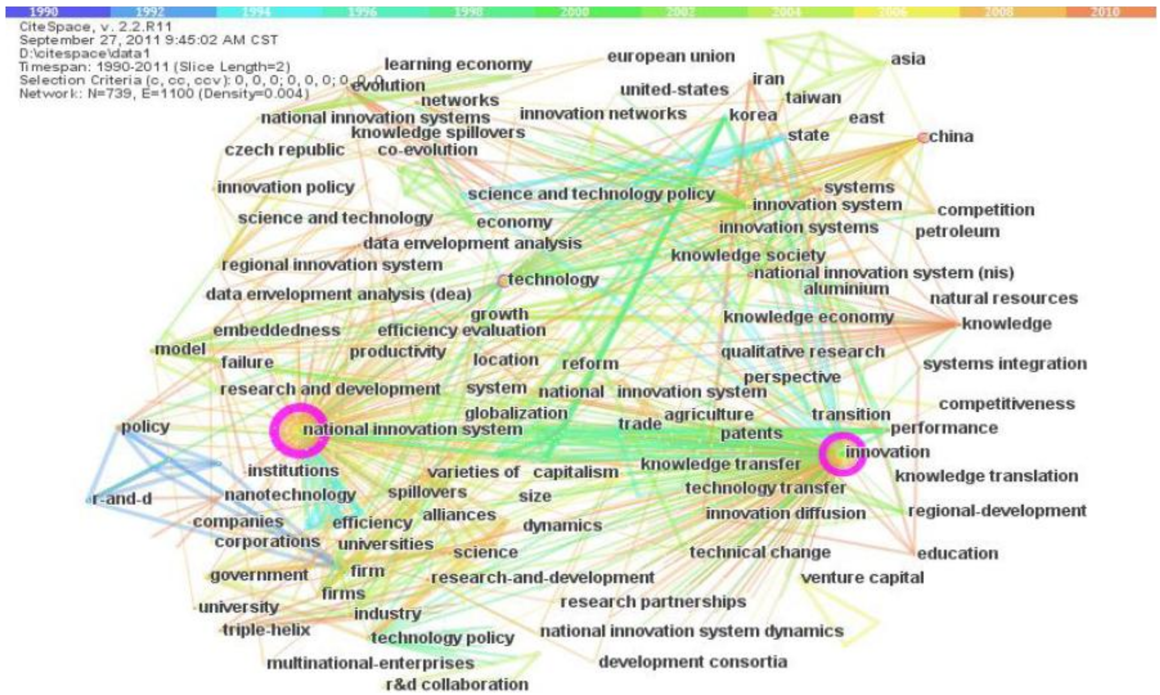

Figure 1 : Clusters of keywords of national innovation system

Cluster 1 includes the empirical analyses of different national innovation systems. Foreign scholars have paid more attention to some kinds of new economic entities recently, such as China, Taiwan, Korea, Iran and other Asian countries and regions. But America and Norway are also important parts of the research fields. Cluster 2 is mainly about researches of national innovation system from the perspective of institutions and policies. Cluster 3 focuses on the knowledge flows and learning to study national innovation system[6]. Cluster 4 is made up of studies in the view of triple helix angle to study national innovation system[7].

Cluster 6 concentrates on the research methods, including DEA, performance evaluation, productivity evaluation, etc.

Cluster 5 studies national innovation system from networking point of view, which started after 2007 and belong to the hot issues of national innovation system nowadays. This kind of research takes social network as main approach and put all innovation agents into the network to analyze their interaction, knowledge flows and study mechanism, etc.

In the perspective of networking model, the agents in the national innovation system incorporate colleges, research institutes, government, companies, financial institutions, intermediaries, etc. It is put forward in the Outline of the National Program for Long- and Medium-Term Scientific and Technological Development (2006-2020) that to comprehensively promote the construction of national innovation system with Chinese characteristics, to establish the technological innovation system with companies as agents and combination of industry-university-research, to develop research universities and build the knowledge innovation system in which the scientific researches integrate with higher education, to construct regional innovation system with distinctive characteristics and advantages, to build scientific intermediary service system with socialization and networking[8]. In the same time, knowledge innovation and technology innovation are the core of national innovation system, and the fifth model of technology innovation lays emphasis on the connection impacts knowledge flows and knowledge management have on innovation network. Therefore, national innovation system consists with integrated innovation networking model when it comes to the effects of knowledge innovation. As a result, this paper believes that the consistency of national innovation system and the fifth networking model of technology innovation offer a new thinking for the study of national innovation system, namely the research of the interaction among agents in national innovation system from the perspective of system integration and networking model.

Previously, networking analyses of national innovation system regarded the whole system as a big network with companies, colleges, research institutes, government and intermediaries spreading on its notes, which focused on their interaction with each other[9]. Nevertheless, this paper not only treats the national innovation system as a knowledge network, but also believes that this network is a huge one, including a large number of sub-networks in which there are different agents interacting with each other[10]. However, agents in different sub-networks play distinctive roles and it is essential for every sub-network to function well so that the huge network can operate normally.

Moreover, this paper decomposes national innovation system into three knowledge networks: scientific research network, technology development network and technology diffusion network. Based on the three networks, index system of national innovation systems networked evaluation can be built.

THE FRAMEWORK OF THREE-NETWORK COMBINATION AND THE ASSESSMENT INDEX SYSTEM

This paper divides national innovation system into three networks from the perspective of knowledge network: scientific research network, technology development network and technology diffusion network

Scientific research network

Scientific research network pays more attention to colleges and research institutes and this sub-network lays the foundation of national innovation system, providing innovation foundation and guarantee for the whole network. It consists of colleges and universities, government laboratories, industrial laboratories and nonprofit organizations. All the agents collaborate with each other and engage in research and development of basic science and technology[11]. It is an efficient way to gauge how robust the scientific research network connection is by studying the collaborated theses. It is possible to figure out the tightness of the scientific research network through researching the aggregation of collaboration, the higher the level of aggregation, whose coauthors come from different agents is, the higher the integrity of the knowledge is. Then it can boost the increase of innovation network's performance.

Technology development network

Technology development is a process in which achievements of scientific research are applied to production through further innovation, so that commercialization can be realized.

American economist Freeman differentiated technological innovation diffusion from technological innovation and invention strictly. He insisted that "invention is idea, paper or model which is put forward to improve design, production, craft or institution, which is usually patented but not necessary to become technology innovation. In terms of economics, innovation means those new productions and craft designs which are initially introduced into commercial trade." But technological innovation diffusion happens after invention or technology innovation, and is concerned with the dissemination process of technology innovation in market[12].

Technology development network is the network which applies achievements of scientific researches to companies' production. From its definition, it is clear that companies are the agents of the network. However, this network should also include government, research institutes, financial institutions, intermediaries and other agents. With the application of social networking analysis to every research field recently, scholars have brought up the approach of using patent-citation network and social network to analyze the networking features of technological diffusion. Knowledge diffusion networks of different organizations and nations can be established by patent-citation network, and it is also feasible to gauge the network by analyzing the key notes and core networks through social network.

Technology diffusion network

As to the carriers of technological diffusion, technological diffusion happens in the way like FDI and technological trades at macroscopic level. While at the microcosmic level, it happens by information communication among companies and staff[12]. So technology diffusion network of national innovation system is also the one which is compounded of technological trade agents, FDI networks and technological users. Agents involved in the technology diffusion network are domestic and foreign companies, multinational corporations, colleges and universities and intermediaries. In this network, technological market driven by government plays a critical role, technological trades and foreign investments rely on mature mechanism of technological market and sound environment of law and policy to a large extent.

Technological trade agents in different areas take their advantages of informationizion, networking and large scale to integrate scientific and technological resources and become the supporting service systems of technological transfer which have multi-functions of information collection and distribution, technological assessment, technological counsel, market forecast, project incubation and investment and financing[13], influencing the formation and development of technology diffusion network.

The basic framework of assessment index system of national innovation system

According to the feature that scientific research network, technology development network and technology diffusion network compose the national innovation system and the validity of the data, this paper constructs the networking index systems of national innovation system with “scientific research network”, “technology development network” and “technology diffusion network” as its first-grade index, as is shown in figure 2.

THE DATA SOURCE, MEASUREMENT AND EVOLUTIONARY TREND OF THE EVALUATION INDEX

The data source of the evaluation index

This paper mainly uses the following indicators: the

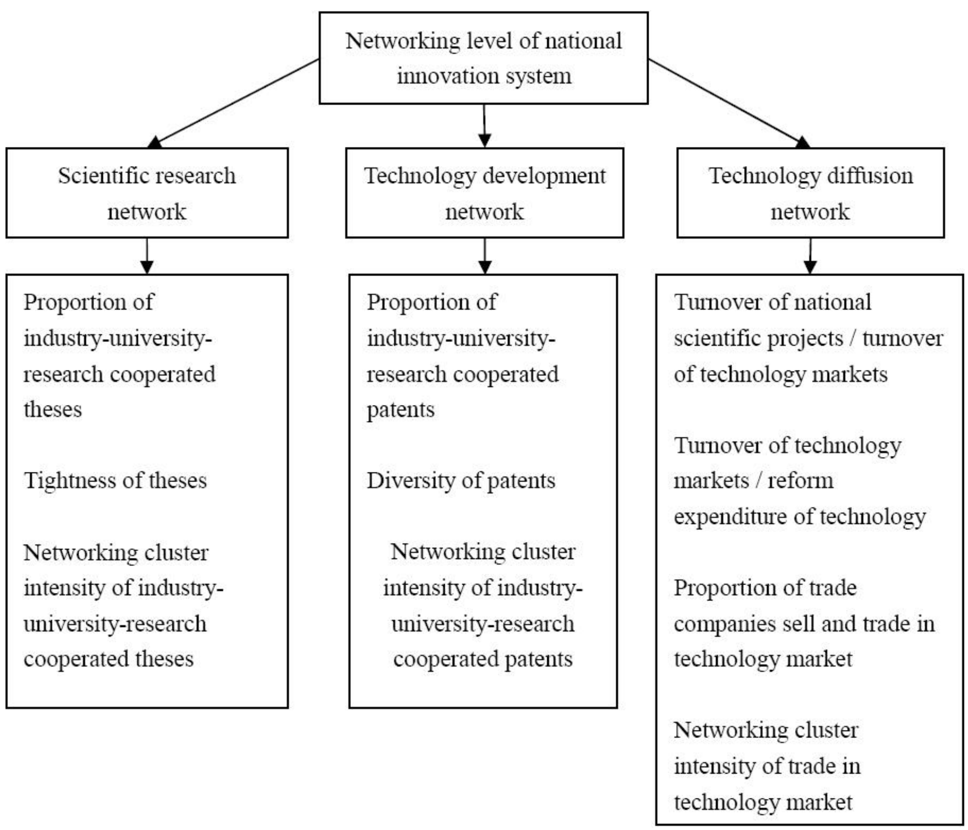

Figure 2 : Framework of three-network combination of national innovation system

proportion of production-study-research cooperation papers (X_1), the tightness of production-study-research cooperation paper group (X_2), paper concentration (X_3), the patent proportion of production-study-research cooperation (X_4), the tightness of production-study-research cooperation patent network group (X_5), patent diversity (X_6), the project sales of the national science and technology/technological market turnover (X_7), technological market turnover/the funds of technological reform (X_8), the proportion of company sales in technological market deals (X_9), the tightness of trading network group in technological market (X_{10}). The relevant data about "papers" are from "China National Knowledge Internet (CNKI)". We use "company", "factory" and "group" as keywords to identify companies in China National Knowledge Internet, use "university", "school" as keywords to recognize universities and use "research institute" and "academy" as keywords to identify research institutions. Retrieve the literature that contains at least two of the three main body, and use years as measuring unit. The relevant data on "patents" are from "China patent database"; The rest basic data are from China statistical yearbook (2001-2011 years) and the statistics of the annual report on the national technology market (2004-2012 years).

The measurement of some important indicators

(1)The calculation of network group tightness

The indicators of network group tightness that X_2, X_3 and X_{10} used are network analysis indicators this paper proposed, mainly measure the degree of the close contact among the network group unit. The relation between this concept and the concept of "centrality" are closely linked. "Overall center" is a concept that is proposed by Freeman, on the basis of the "regional center". In the social network measurement, two points are connected through a way which contains different lines and the length of the way is measured by the numbers of the lines that constitute the way. In graph theory, the distance between two points is measured by the length of the shortest path between two points and the shortest path is called "shortcut". If the distances between a point and many other points are very short, we call this point is the center of the whole. The whole central degree of this point is the sum of the short distance between this point and every other point in the picture.

Center degree is one of the most important and commonly used concepts to analyze the social network. It's about the measurement concept of the centricity position of the actors in the social network and it reflects the differences of position or advantage of the actors in the social network structure[14]. In the past social network study, the scholars respectively put forward the concept of relative closely center degree and group closely center degree which represent the independent degree between the network group unit. Their measure equations are respectively:

Relatively central tightness:

$$C_c = \frac{N-2}{\sum_{j=1}^{n} d(n_i, n_j)} \tag{1}$$

Cluster central tightness:

$$C = \frac{(2N-3)\sum_{i=1}^{n}(C_{c\max} - C_{ci})}{(N-2)(N-1)} \tag{2}$$

The tightness of the network group this paper proposed is on behalf of the degree of the close contact among the network group unit. The higher the connection degrees of the units are, the bigger the network group tightness is. As the centrality degree represents the independent degree between the network group unit, network groups tightness is measured by the inverse of the closely centrality degree of the network group, that is:

$$\mathbf{D=C^{-1}} \tag{3}$$

(2) Calculation of patent diversity

In the new growth theory, the technological innovation showed the improvement of "product diversity", the same as the increasing of the product categories brought about new products development. In the model (4) of Aghion and Howitt, Y_t, L, x_i, M_t are respectively on behalf of output of the final product0input of the labor0input of the i-th intermediate products and the types of the intermediate products. Their models are

$$Y_t = L^{1-\alpha}\int_0^{M_t} x_i^{\alpha} di \tag{4}$$

Diversity in the measurement can be defined as (there are also other defined forms):

$$H = -\sum_{i=1}^{n} \log(P_i / Z) / (P_i / Z) \qquad (5)$$

In formula (5), in terms of patent network, n0H0Z0 are respectively on behalf of the total numbers of the main body of the patent network0the diversity of the main body of the patent network0the patent numbers of the patent network and the patent numbers of the subject i.

Virtually, diversity is a kind of "negative entropy", which represents the amount of information of the network group to some extent. The greater the amount of information is, the more creativity it may be.

The measurement and evolution trend of the network evaluation index of the scientific research

(1)The proportion of the production-study-research cooperation papers of the total (X_1)

The production-study-research cooperation papers mean that of all the papers, selecting the papers coauthored by the enterprises, universities and research institutions. As there are many key words of enterprises, universities and research institutions, we use "company", "factory" and "group" as keywords to identify companies in China National Knowledge Internet, use "university", "school" as keywords to recognize universities and use "research institute" and "academy" as keywords to identify research institutions from SSCI database. Retrieve the literature that contains at least two of the three main body, and use years as measuring unit. From the statistical results in terms of the two indicators that include the number of papers and the paper proportion, it shows a rising trend from 2000 to 2010, while the cooperation between universities and research institutes, universities and research cooperation accounts for the largest proportion in production-study-research cooperation, that is to say production-study-research cooperation is relatively close and frequent; Secondly, it is the cooperation between production and study. We can say, in the scientific research network, university is undoubtedly in the dominant position of the network. From the rising trend, whether the numbers of production-study-research cooperation papers, an absolute number or the proportion of production-study-research cooperation papers, a relative number, it is higher than that of 2000, on the whole. It is proved from the point of scientific research network, the intensity of production-study-research cooperation increased year by year in China, as is shown in figure 3.

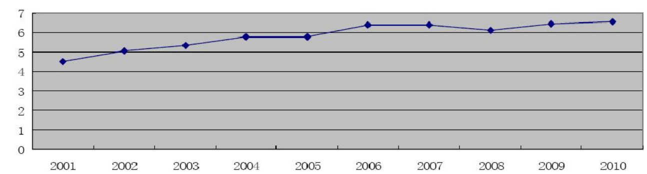

Figure 3 : Production-study-research cooperation paper proportion (unit: %; data sources: CNKI)

(2)The tightness of production-study-research cooperation paper group (X_2)

We can calculate the tightness of production-study-research cooperation paper group according to formula (3), the calculation results of this index is shown in TABLE 1. Its figure increased on the whole, but there is a big fluctuation.

(3)Research and development spending/GDP (X_3)

The data of this index are shown in TABLE 1. Its figure is increasing year by year and catching up C the average level of developed countries (2.5%).

The measurement and evolution trend of the network evaluation index of the technology development

(1)The patent proportion of production-study-research cooperation (X_4)

Similar to production-study-research cooperation

TABLE 1 : The evolution of science research network indicators

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
The proportion of the production-study-research cooperation papers of the total（%）	4.5	5.1	5.3	5.8	5.8	6.4	6.4	6.1	6.4	6.5
The tightness of production-study-research cooperation paper group	1929	696	867	1227	2096	1711	2138	1557	2520	3609
Research and development spending/GDP（%）	0.95	1.07	1.13	1.23	1.32	1.39	1.4	1.47	1.7	2

paper proportion, the patent proportion of production-study-research cooperation refers to selecting out the patents cooperated by enterprises, universities and research institutions among the integration of all granted patents. As there are many key words of enterprises, universities and research institutions, we use the "company", "factory" and "group" as keywords to identify companies in the search of Chinese intellectual property office patent, use "university", "school", "college" as keywords to recognize the universities and use "institute" and "research" as keywords to identify research institutions. Retrieve the literature that contains at least two of the three main body, and use years as measuring unit.

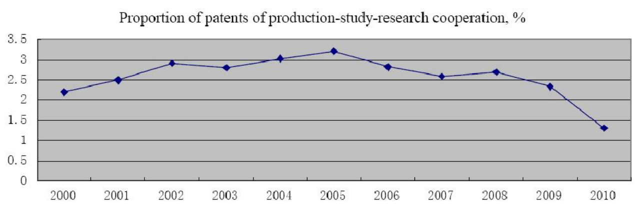

Figure 4 : The patent proportion of production-study-research cooperation in 2000-2010(unit: %; data source: patent retrieval database of Chinese intellectual property office)

As the insufficient situation of the domestic technology demand is changing, enterprises begin to seek more cooperation of colleges and universities, scientific research institutions at home and abroad, and all kinds of production-study-research and the models of cooperation between enterprises including technology alliance will appear more. The characteristics of the generic technology determine cooperation is an effective way of technological breakthroughs. For the industry as a whole, technology breakthroughs are in the relationship of the national economy, and for the generic technology that plays an important leading role in the national economy, they have general characteristics including multidisciplinary cross, more difficult in technique, high complexity, needing long-term technology accumulation and interdepartmental joint research innovation in organizing the implementation. Only the enterprises, industries and each departments of the government coordinate and cooperate, will the key common technology achieve fundamental breakthrough[10].

From the view of the absolute number of the production-study-research cooperation patent, patent number of production-study-research cooperation increase year by year in China. But from the view of the patent proportion of production-study-research cooperation, it basically presents an inverted u-shaped curve form. Namely the cooperation patent proportion descends after the first ascend. Analysis of the reason mainly lies in the growth of the total number of patent cooperation is faster than the growth of the patent, so as to make the patent proportion of production-study-research cooperation decline year by year after reaching the maximum in 2005. It also suggests that the strength of production-study-research cooperation patent is not enough in China.

(2)The diversity of the patent (X_5)

From figure 5, we can see that from the perspective of the division of the main body of patent network (university, college, group, company, factory, etc.), the diversity of China's patent rises year by year. The connection degree in the patent cooperation network of all kinds of innovation main body (university, college, group, company, factory, etc.) is enhancing progressively while their respective characteristics are giving fully functioned.

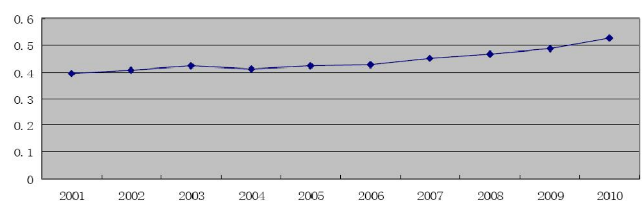

Figure 5 : The constant rise of the patent diversity (from the perspective of the division of the main body of patent network)

(3)The tightness of production-study-research cooperation patent network group (X_6)

The tightness of production-study-research cooperation patent network group represents how closely the links between the patentee of production-study-re-

TABLE 2 : Evolution of the technology development network indicators

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Patent proportion of production-study-research cooperation (%)	2.5	2.9	2.8	3.0	3.2	2.8	2.6	2.7	2.3	1.3
The diversity of patent	0.39	0.41	0.42	0.41	0.42	0.42	0.45	0.47	0.49	0.53
Networking cluster intensity of industry- university-research cooperated patents	827	422	740	673	398	770	798	719	770	1028

search cooperation. The higher the degree of the contact is, the greater the tightness of production-study-research cooperation patent network group is.

TABLE 2 lists the evolution trend of three evaluation indicators in technology development network including proportion of patents, patent diversity and evolution trending data of the tightness of patent cooperation network group.

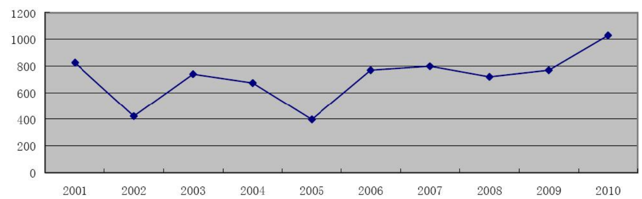

Figure 6 : The change of the tightness of production-study-research cooperation patent network group in 2001-2010

(3)The proportion of company sales in technological market deals (X_9)

Enterprise is the receiving party in technology diffusion, and the indicator of the proportion of company sales in technological market deals reflects the network degree of dissemination and diffusion among the technology receivers in the technology diffusion. In terms of this indicator, it ascended from 38% in 2001 to 86% in 2010.

(4)The tightness of trading network group in technological market (X_{10})

According to formula (3), the tightness of trading network group that has been calculated is shown in TABLE 3. In terms of this indicator, it ascended from 17.7 in 2001 to 28 in 2010.

PRINCIPAL COMPONENT ANALYSES AND THE EVALUATION OF NETWORK LEVEL OF NATIONAL INNOVATION SYSTEM

Principal component analysis

TABLE 4 shows the relative values of the indicators. Principal component analysis can be used to determine weight of 10 indicators. As shown in the last row in TABLE 4. And evaluation of Chinese national innovation system network level can be done as is shown in Figure 7.

The model of the national innovation system network level evaluation is

$$I=\sum_{i=1}^{10}\theta_i X_i \qquad (5)$$

In formula (5), I represents the national innovation system network level evaluation results: X_i represents the i-th evaluation index: θ_i represents the i-th evaluation index weight, the 10 weights determined by the principal component analysis, according to the data in TABLE 4, the contribution rates of the first two principal components were 62% and 17% (which indicated that the two main components extract 78% information of the entire data), so according to these two principal

TABLE 3 : Evolution of the evaluation index of the technology diffusion network (2000-2010)

Years	The project sales of the national science and technology /technological Market Turnover(X_7)	Technological market turnover/ the funds of technological Reform(X_8)	The proportion of company sales in Technological market deals(X_9)	The tightness of trading network group in Technological Market(X_{10})
2001	0.19	0.62	0.38	17.7
2002	0.14	0.59	0.42	19.4
2003	0.19	0.57	0.48	20.2
2004	0.19	0.45	0.57	20.6
2005	0.15	0.56	0.59	20.6
2006	0.22	0.60	0.84	21.2
2007	0.20	0.61	0.86	22.9
2008	0.18	0.57	0.87	19.9
2009	0.19	0.70	0.87	22.0
2010	0.24	1.07	0.86	28

components to determine the index weight, as shown in the last row in TABLE 4.

TABLE 4 : Relative values of the indicators and weights

	The number of production-study-research cooperation papers/ The total number of papers X_1	production-study-research papers tightness cooperation network group X_2	R&D funding/ GDP X_3	Number of Cooperative Lee/ Total number of patents X_4	cooperation lee number tightness network group X_5	Patent diversity X_6	Technological market turnover /Technological innovation funding X_7	National science and technology projects turnover/ Technological market turnover X_8	Technological trading network groups tightness X_9	the proportion of enterprises selling in technology market turnover X_{10}
2001	0.85	0.53	0.48	0.83	0.80	0.74	0.58	0.78	0.64	0.44
2002	0.85	0.19	0.54	0.90	0.41	0.77	0.55	0.60	0.70	0.48
2003	0.86	0.24	0.57	0.93	0.72	0.80	0.53	0.80	0.74	0.55
2004	0.90	0.34	0.62	0.93	0.65	0.78	0.42	0.79	0.75	0.66
2005	0.90	0.58	0.66	0.93	0.39	0.80	0.52	0.64	0.75	0.68
2006	0.92	0.47	0.70	0.94	0.75	0.80	0.56	0.94	0.77	0.97
2007	0.96	0.59	0.70	0.86	0.78	0.85	0.57	0.82	0.83	0.99
2008	0.95	0.43	0.74	0.90	0.70	0.88	0.53	0.76	0.72	1.00
2009	1.00	0.70	0.85	0.78	0.75	0.92	0.65	0.79	0.80	1.00
2010	0.90	1.00	1.00	0.96	1.00	1.00	1.00	0.99	1.00	1.00
The index weights θ_i	0.02	0.11	0.12	0.05	0.11	0.12	0.13	0.12	0.13	0.08

Evaluation of Chinese national innovation system network level

China's national innovation system network level shows a steady upward trend since 2000 and rose from 0.64 in 2001 to 0.985 in2 010 as is shown in figure 7.

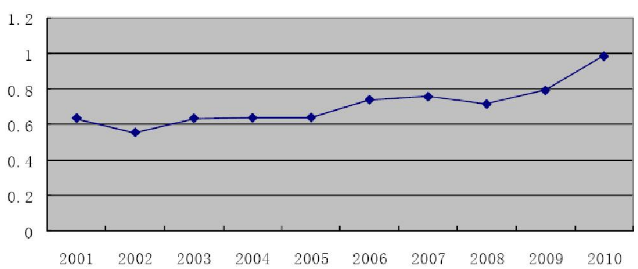

Figure 7: Evolution of Chinese national innovation system network level

Discussion on the evaluation results

(1) The level of the national innovation system network in a way represents the development of the national innovation system. In 2000, if the various elements of the national innovation system (enterprises, universities, institutions, agencies, etc.) do not contact closely enough, national innovation system is still in the primary stage of development; then, by 2010, national innovation system have already begun to enter the more advanced stages of development, degree of contact of the elements has been relatively tight, showing more complete network characteristics.

(2) From the weights of national innovation system network level estimated index, weight of scientific research network is 0.26, weight of the technological development network is 0.28, weight of technology diffusion network is 0.46, so at this stage, the national innovation system development center tends to technology diffusion stage of science-technology-economic, which is decided by development of Science and Technology-economic at this stage. In this opinion, in terms of the innovation model, from 2000 to 2010, China's emphasized original innovation (closer to scientific research networks), integrated innovation, as well as the introduction of absorption and innovation. In the next decade

(2011-2020), the time of original innovation and introduction of absorption and innovation, China should pay more attention to integrated innovation, so that the weight of scientific research networks, technology development network and technology diffusion network would be more balanced.

(3) For each index weights, the "proportion of production-study-research cooperative papers accounted for total number", "proportion of cooperative patent ratio" weights were 0.02 and 0.05, much lower than other ones, indicating that strengthening research cooperation and collaborative innovation is still the key task of national innovation system contribution.

(4) From the sub-indicators, indexes on the rise are "proportion of production-study-research cooperative papers accounted for total number," "tightness of production-study-research cooperative networking groups", "R&D expenditure/GDP", "patent diversity", "technological market turnover/ technological innovation funds ","proportion of corporate betrayal in technology market transactions"," technology trading network all units tightness". And the recent falling index is "production-study-research cooperative patent ratio". Thus the next target of this study are to analyze the reasons of the decline of "proportion of production-study-research cooperative patents" and great volatility index "tightness of production-study-research cooperative networking groups" and what causes "national science and technology projects turnover/technological market turnover" volatility. Finally, countermeasures should be worked out in order to promote better and faster development of national innovation system.

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