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Construction of the Evaluation Index System for Innovation Ability of Regional Science and Technology in China

SUN Xiaokun * SUN Qigui
School of Public Affairs, University of Science and Technology of China,No.96 JinZhai Road Baohe District, Hefei Anhui 230026, China

Abstract
To scientifically construct a more optimized evaluation index system for innovation ability of regional science and technology in China, this paper is based on the existing research and selects the relevant academic literatures from CNKI. Then use the social network analysis method and UCINET software centrality analysis to extract the indicators step by step. The first-level indicators include the basis of scientific and technological innovation, the investment of scientific and technological innovation, the output of scientific and technological innovation and the benefit of scientific and technological innovation. The second-level indicators include the awareness of science and technology, human investment, high-tech industrialization, etc. The third-level indicators include the number of patent application, R&D expenditure, the sales revenue of high-tech industry, etc. Finally, the evaluation index system for innovation ability of regional science and technology consists of 4 first-level indicators, 10 second-level indicators and 32 third- level indicators.
Keywords: the evaluation index system, social network analysis, innovation ability of regional science and technology

1. Introduction

Innovation is the soul of national progress, and regional innovation is the key factor for the sustainable development of regional economy. Innovation of regional science and technology is the core driving force for improving the level of regional innovation and development. It is common knowledge that improving the innovation ability of regional science and technology has become an important strategic choice for a country or region to enhance comprehensive competition strength.

The innovation ability of regional science and technology refers to the ability that a region uses the unique resource conditions to promote regional economic development and it is the unity of the interaction of resource elements in the region (Shan Lu 2007). It can transform knowledge into new products, new process, new services (Shaohua Jiang 2008). The scientific, objective and accurate evaluation of the innovation ability of regional science and technology helps us to understand the status quo of regional development and clarify its own advantages and gaps so as to point out the direction for upgrading the innovation ability of regional science and technology and realize the efficient integration and optimal allocation of resources. The research of the innovation ability of regional science and technology originated from the theory of foreign regional innovation system at first. The concept of the regional innovation system was first proposed by Cooke in 1992 in *Regional Innovation Systems: Competitive Regulation in the New Europe*.

The construction elements of evaluation index system for innovation ability of regional science and technology mainly relate to innovation environment, education level, knowledge stock, human capital, economic structure, innovation performance, innovation system, investment in industrial R & D, regional innovation policy and enterprise technological innovation (Wiig & Wood 1995; Cooke *et al.* 1998; Porter *et al.* 2000; Riddel *et al.* 2003; Ronde & Hussler 2005; Tödtling & Trippl 2005; Tura *et al.* 2008; Coenen *et al.* 2017). The research methods mainly include factor analysis, data envelopment analysis, panel data analysis, case study and literature research (Lawson & Lorenz 1999; Doloreux 2003; Zabala-Iturriagagoitia *et al.* 2007; Pinto & Guerreiro 2010; Broekel 2015; Maghsoudi *et al.* 2015).

Chinese scholars start the research on innovation ability of regional science and technology comparatively late, but still achieve some relevant research results. On the one hand, the index system framework is relatively systematic, which is mainly divided into 2 or 3 indicator levels. Most of them include three index levels. The first level usually involves elements such as innovation environment, innovation input, innovation output, and innovation effectiveness. On the other hand, the index evaluation method is more objective, and mainly adopts the quantitative analysis method. These methods include principal component analysis, factor analysis, gray relational analysis, fuzzy comprehensive evaluation and analytic hierarchy process (Juhua Shen 2005; Taozhu Feng & Xiaofeng Li 2008; Xinghua Jiang 2012; Yawei Wang & Ke Han 2012; Lianghu Mao & Ying Jiang 2016).

However, the researches on the evaluation index system of regional science and technology innovation ability in China are mostly based on the construction of the evaluation index system in a particular research context with some subjectivity and randomness. First, the nature of indicators is similar, such as the number of research and development personnel and the number of research and development personnel per 10,000 population (Taozhu Feng & Xiaofeng Li 2008), so the difference between the indicators is not obvious. Second, some indicators are not specific, such as environmental quality index (Tao Chang *et al.* 2015), which needs to be further elaborated. Third, the indicator level is not clear enough. For example, indicators such as R&D expenditure intensity (Guohong Chen *et al.* 2015) are inconsistent with the indicator levels that belong to different indicator systems. Finally, the indicator structure is not optimized. For instance, some indicator systems (Li Xiang 2016) seems simple, which may lead to incomplete coverage of the indicator system. Some indicator systems (Wenxian Jiang 2016) are too complicated, including the rate of forest cover (Yawei Wang & Ke Han 2012) and other indicators with low correlation coefficient. So the index selection should be weighed in the process of construction of index systems.

Although the above index systems can make an evaluation and analysis of innovation ability of regional science and technology, the scientificity and applicability still have some shortcomings. It is difficult to draw a more accurate assessment result. The evaluation index system of innovation ability of regional science and technology needs to be improved and optimized urgently. In view of this, based on the existing research, this paper uses the social network analysis method, through the gradual extraction of indicators and explanation, in order to systematically build a more optimized evaluation index system of innovation ability of regional science and technology in China.

2. The Construction Idea and the Research Sample

2.1 The Construction Idea

This article mainly uses the social network analysis method to construct the evaluation index system of regional science and technology innovation ability. Social network analysis refers to the method of quantitative research on the structure formed by social relations. It can clearly present the relationship between different elements at the micro, meso and macro levels and has been used to explain sociology, management science, economics and other fields of important tools. Social network analysis methods include central analysis, cohesion subgroup analysis, core-edge analysis and structural peer analysis. The central analysis is one of the focuses of social network analysis. This paper selects the centrality analysis. The centrality analysis mainly analyzes the centrality of the entire network node, while the centrality is used to measure the degree of the individual in the entire network center, at the same time, it can reflect the importance of the point in the entire network. This is not only the key of the index extraction, but also guarantees the scientificity, accuracy and authority of the index extraction.

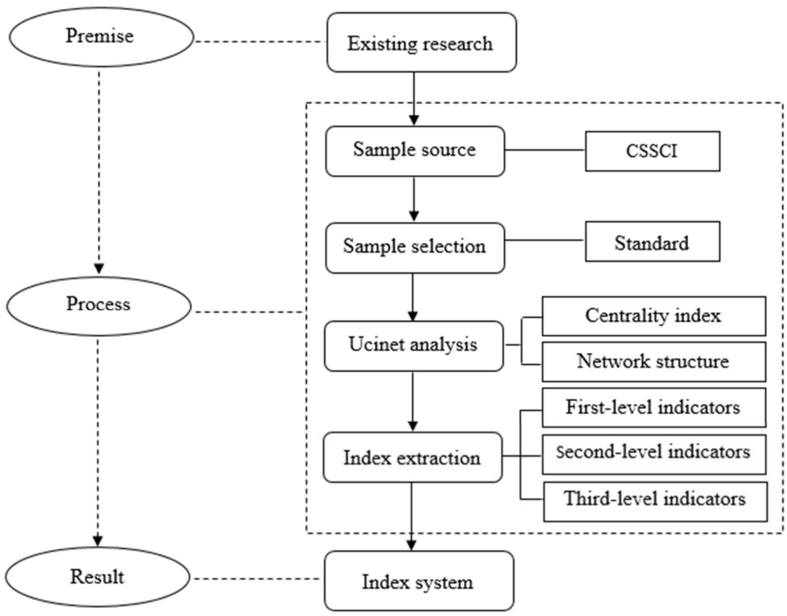

Figure 1. The Construction Idea

The specific idea of building the index system of innovation ability of regional science and technology is shown in Figure 1, which is mainly divided into three stages: the first stage is the premise, that is, the existing achievements and shortcomings; the second stage is the process, which mainly includes sample source, sample selection, Ucinet analysis and index extraction. The third stage is to build the index system. Based on the above research, the final construction of evaluation index system for innovation ability of regional science and technology is completed.

2.2 The Research Sample

In order to more clearly reflect the status quo of research on the construction of evaluation index system for innovation ability of regional science and technology in China, this paper will focus on the study of sample sources in Chinese journals. In the meantime, in order to accurately select journals with academic representation, this paper selects CSSCI from CNKI as the research sample source database. A "thematic search" was conducted using "regional technology innovation" as a search field, with a time span of 2001 to 2017, and 289 related articles were retrieved. The search time was January 23, 2018. In this paper, 289 journal articles retrieved from the above CSSCI database were studied and screened one by one according to the following screening criteria：(1) Is the topic of literature research relevant to the construction of valuation index system for innovation ability of regional science and technology? (2) Whether the content of the literature clearly put forward the evaluation index system? Through the above screening work, the study finally gets 28 periodical literature as the research sample, which provides the data source for the social network analysis of the evaluation index system in the next stage.

3 The Specific Design

3.1 First-Level Indicators

Among the 28 journal articles screened, there are 18 evaluation index systems involving three levels and the remaining 10 are two levels of evaluation index system. It is noteworthy that, from the point of view of the connotation of indicators, the first 10 indicators listed above and second-level indicators are equivalent to the other 18 listed the first-level indicators and third-level indicators, so this paper extracts the first-level indicators based on the above 28 articles. First of all, 28 literatures were studied one by one to extract a summary of indicators, a total of seven primary indicators; Second, the seven first-level indicators with the authors (here referring to the first author, the same below) to establish a relationship matrix, and converted into data processing format required by Ucinet software；Finally, we used Network-Centrality to conduct a centrality analysis of the first-level indicators. The statistical results of the centrality index of first-level indicators are shown in Table 1.

Table 1. The Centrality Index of First-Level Indicators

X1 First-level indicators	Centrality	Standardization centrality	Proportion
X1-1 The output of scientific and technological innovation	28.000	82.353	0.136
X1-2 The investment of scientific and technological innovation	26.000	76.471	0.126
X1-3 The basis of scientific and technological innovation	22.000	64.706	0.107
X1-4 The benefit of scientific and technological innovation	22.000	64.706	0.107
X1-5 Research and development capability	2.000	5.882	0.010
X1-6 Diffusion of innovation of science and technology	2.000	5.882	0.010
X1-7 Knowledge mobility	1.000	2.941	0.005
Overall average	5.886	17.311	0.029

As can be seen from Table 1, the average value of the centrality index in the entire network is 5.886, the standardization centrality index is 17.311. At all first-level indicators, the output of scientific and technological innovation (28.000), the investment of scientific and technological innovation (26.000), the basis of scientific and technological innovation (22.000) and the benefit of scientific and technological innovation (22.000) exceed the average value of the entire network index. And the standardized centrality indices of the four indicators also exceeded the mean of the standardized centrality indices of the entire network, indicating the importance of the above indicators in the entire network. However, the centrality index and standardized centrality index of the other three indicators, research and development capability（2.000）, diffusion of innovation of science and technology（2.000）and knowledge mobility（1.000）, are all lower than the average value of the whole network, and the index difference is rather wide.

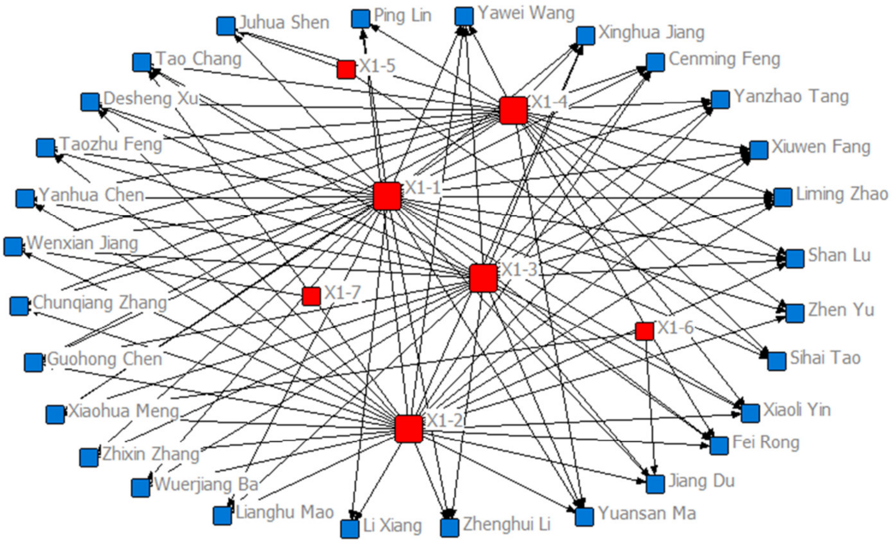

Figure 2. The Network Structure of First-Level Indicators

Visualize-Net Draw generates the network structure of first-level indicators, as shown in Figure 2.The blue box in the peripheral region of Figure 2 represents the author, the red box in the middle region represents the index, and the larger the red box indicates that the index is larger and the degree of importance is higher. It can be intuitively learned from Figure 2 that the boxes of the investment of scientific and technological innovation, the output of scientific and technological innovation, the basis of scientific and technological innovation and the benefit of scientific and technological innovation are more prominent. However, the boxes of research and development capability, diffusion of innovation of science and technology and knowledge mobility are relatively small. In summary, this paper will eventually retain these indicators, that is, the investment of scientific and technological innovation, the output of scientific and technological innovation, the basis of scientific and technological innovation and the benefit of scientific and technological innovation.

3.2 Second-Level Indicators

Similar to the process of extracting first-level indicators, we first need to clarify the data sources of the second-level indicators. Given that of the 28 selected articles, only 18 involved 3 indicator levels, these 18 are the data sources for the second-level indicators. By studying the literature, a total of 25 second-level indicators were extracted, these 25 indicators together with the authors to establish the relationship matrix into data processing format required by Ucinet software. Using Network-Centrality for center analysis, the final results of the second-level index centerity index statistics are shown in Table 2.

Table 2. The Centrality Index of Second-Level Indicators

X2 Second-level indicators	Centrality	Standardization centrality	Proportion
X2-1 The awareness of science and technology	18.000	42.857	0.048
X2-2 Financial input	18.000	42.857	0.048
X2-3 Direct output of scientific and technological activities	18.000	42.857	0.048
X2-4 Changes in the mode of economic growth	18.000	42.857	0.048
X2-5 Human investment	17.000	40.476	0.046
X2-6 High-tech industrialization	16.000	38.095	0.043
X2-7 Environmental benefit	13.000	30.952	0.035
X2-8 Improvement of quality of life	13.000	30.952	0.035
X2-9 Enterprise Technology Innovation	13.000	30.952	0.035
X2-10 Scientific research material conditions	11.000	26.190	0.030
X2-11 Optimization of industrial structure	7.000	16.667	0.019
X2-12 Resident income and employment	4.000	9.524	0.011
X2-13 Technology infrastructure	3.000	7.143	0.008

X2-14 Science and technology policy environment	2.000	4.762	0.005
X2-15 Industry International Competitiveness	2.000	4.762	0.005
X2-16 Market demand	2.000	4.762	0.005
X2-17 The rate of technology contribution	2.000	4.762	0.005
X2-18 Information environment	2.000	4.762	0.005
X2-19 Foreign Direct Investment	1.000	2.381	0.003
X2-20 Knowledge exchange	1.000	2.381	0.003
X2-21 Natural resource endowment	1.000	2.381	0.003
X2-22 The quality of workers	1.000	2.381	0.003
X2-23 Environmental support	1.000	2.381	0.003
X2-24 Entrepreneurial level	1.000	2.381	0.003
X2-25 Innovative service environment	1.000	2.381	0.003
Overall average	8.651	20.598	0.023

As can be seen from Table 2, the average value of the centrality of the entire network is 8.651, and the average of the standardization centrality index is 20.598. The second-level indicators, such as the awareness of science and technology, scientific research material conditions, whose centrality index and standardized centrality index both exceed the mean value of the entire network, should be preserved. The other indicators of the centrality of the index and the standardization centrality index are lower than the entire network average.

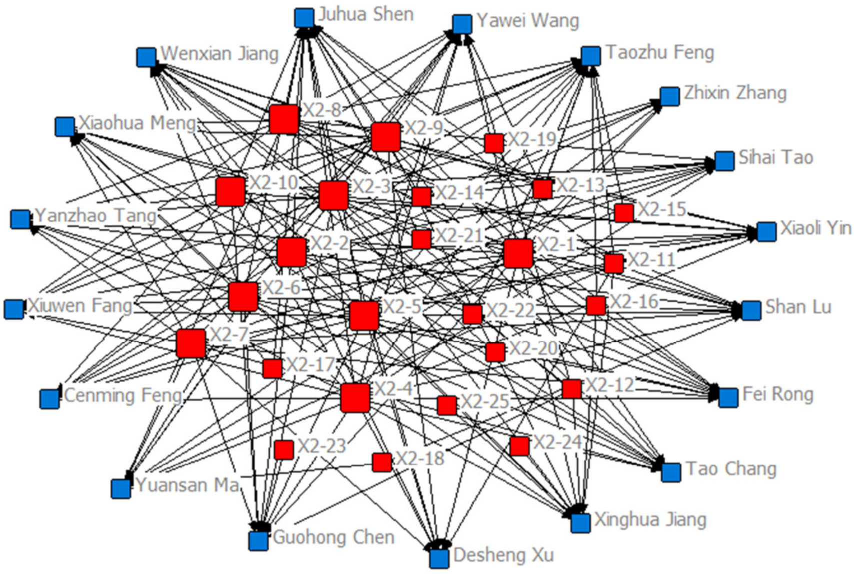

Figure 3. The Network Structure of Second-Level Indicators

Use Visualize-Net Draw to generate the network structure of second-level indicators, as shown in Figure 3. As can be seen from Figure 3, there are 10 indicators are more prominent, such as the awareness of science and technology, financial input, scientific research material conditions, etc. The red boxes of the other 15 indicators are smaller, which also validate the scientificity of the analysis results of the centrality index in table 2. So the above 15 indicators are discarded and only retain 10 indicators.

3.3 Third-level indicators

The second-level indicators of ten documents are similar to the third-level indicators listed in the remaining 18 articles. Therefore, the above second-level indicators are taken as the third-level indicators together to form the third-level indicator data sources. By combing the literature, a total of 213 third-level indicators are extracted, and then these 213 third-level indicators with the authors form the relationship matrix. These indicators are translated into the data processing formats required by Ucinet software. Network-Centrality analysis is used to generate the results of three-level index centering index analysis. In view of the large number of third-level indicators, limited to space, so this paper lists only the average above 28 indicators. New product output value and average annual wage of employed persons in scientific research and technology services are also retained.

Eventually, the centrality index of third-level indicators is shown in Table 3.

Table 3. The Centrality Index of Third-Level Indicators

X3 Third-level indicators	Centrality	Standardization centrality	Proportion
X3-1 Scientific and technical personnel	24.000	10.000	0.020
X3-2 Per capita GDP	23.000	9.583	0.019
X3-3 The number of patent application	20.000	8.333	0.017
X3-4 R&D investment intensity	20.000	8.333	0.017
X3-5 R&D expenditure	19.000	7.917	0.016
X3-6 Local financial education appropriation accounts for the proportion of local financial expenditure	19.000	7.917	0.016
X3-7 The number of scientific papers	17.000	7.083	0.014
X3-8 Technical market contract turnover	17.000	7.083	0.014
X3-9 Comprehensive energy consumption per 10,000 yuan GDP	16.000	6.667	0.014
X3-10 Invention patents authorized amount	15.000	6.250	0.013
X3-11 High-tech products exports accounted for the proportion of total exports	15.000	6.250	0.013
X3-12 The number of patents granted	14.000	5.833	0.012
X3-13 The number of state-level science and technology award results	14.000	5.833	0.012
X3-14 Sales revenue of new products accounted for the proportion of main business revenue	14.000	5.833	0.012
X3-15 Enterprise R&D expenditure accounting for the proportion of product sales revenue	14.000	5.833	0.012
X3-16 Environmental quality index	12.000	5.000	0.010
X3-17 R&D personnel equivalent to full-time equivalent	12.000	5.000	0.010
X3-18 Newly increased fixed assets in scientific research and technology services occupies newly added fixed assets to the whole society	12.000	5.000	0.010
X3-19 High-tech industries added value	11.000	4.583	0.009
X3-20 The number of R&D institutions	10.000	4.167	0.008
X3-21 Per capita postal and telecommunications volume	10.000	4.167	0.008
X3-22 The number of Internet users	10.000	4.167	0.008
X3-23 The number of college students	8.000	3.333	0.007
X3-24 Local financial education appropriation accounts for the proportion of local financial expenditure	8.000	3.333	0.007
X3-25 Actual utilization of foreign capital	7.000	2.917	0.006
X3-26 High-tech industry sales revenue	6.000	2.500	0.005
X3-27 GDP growth rate	6.000	2.500	0.005
X3-28 Scientific research equipment original price	6.000	2.500	0.005
X3-29 New product output value	1.000	0.417	0.001
X3-30 Average annual wage of employed persons in scientific research and technology services	1.000	0.417	0.001
Overall average	4.905	2.044	0.004

Visualize-Net Draw can generate the network structure of third-level indicators, as shown in Figure 4.

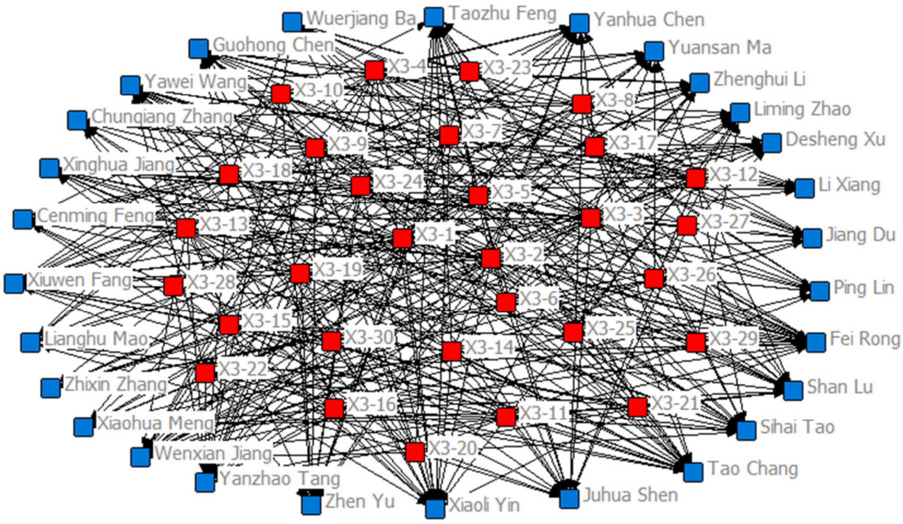

Figure 4. The Network Structure of Third-Level Indicators

As can be seen from Table 3, the average value of the centrality index of the entire network is 4.905, and the average of the standardization centrality index is 2.044, of which, all the 28 indices whose indices are above the average value are all reserved. It is worth pointing out that environmental quality index is relatively weaker in measurability due to its general connotation. Based on the existing research results and comprehensively considering the availability and authority of statistical data, the paper elaborates on the indicator from the perspective of "three wastes" and decomposes it into the proportion of days in which air quality reaches or exceeds the secondary level, comprehensive utilization of industrial solid waste and centralized treatment rate of urban sewage treatment plant.

In addition, two indicators of new product output value, average annual wage of employed persons in scientific research and technology services are retained. The main reasons are as follows: First, new product output value refers to the output value of new products produced by enterprises, to a certain extent, represents the level of innovation capability of enterprises, and can explain the technological innovation of the second-level indicators. And the two indices Values are not much different from the average of the entire network. Second, for average annual wage of employed persons in scientific research and technology services, although the two index values of the indicator are lower than the average value of the entire network, the indicator shows the science and technology awareness of the second-level indicators from the aspect of incentive perspective with certainty the rationality. Based on the above reasons, the final determination of retaining these two indicators, together with other indicators constitute a three-level indicator.

To sum up, this paper summarizes the evaluation index system for innovation ability of regional science and technology proposed by 28 selected core documents, adopting social network analysis methods. Ucinet software centrality analysis of the indicators are extracted step by step, and ultimately this paper build the evaluation index system for innovation ability of regional science and technology in China, as shown in Table 4.

Table 4. The Evaluation Index System for Innovation Ability of Regional Science and Technology

First-level indicators	Second-level indicators	Third-level indicators
The basis of scientific and technological innovation	The awareness of science and technology	The number of patent application
		Average annual wage of employed persons in scientific research and technology services
	Scientific research material conditions	Newly increased fixed assets in scientific research and technology services occupies newly added fixed assets to the whole society
		Scientific research equipment original price
The investment of scientific and technological innovation	Human investment	The number of R&D institutions
		Scientific and technical personnel
		R&D personnel equivalent to full-time equivalent
		The number of college students
	Financial input	R&D expenditure
		Actual utilization of foreign capital
		R&D investment intensity
		Enterprise R&D expenditure accounting for the proportion of product sales revenue
		Local financial education appropriation accounts for the proportion of local financial expenditure
		Local financial scientific and technological appropriations account for the proportion of local financial expenditure
The output of scientific and technological innovation	Direct output of scientific and technological activities	The number of patents granted
		Invention patents authorized amount
		The number of state-level science and technology award results
		The number of scientific papers
		Technical market contract turnover
	High-tech industrialization	High-tech industries added value
		High-tech industry sales revenue
		High-tech products exports accounted for the proportion of total exports
	Enterprise technology innovation	Sales revenue of new products accounted for the proportion of main business revenue
		New product output value
The benefit of scientific and technological innovation	Changes in the mode of economic growth	Per capita GDP
		GDP growth rate
		Comprehensive energy consumption per 10,000 yuan GDP
	Improvement of quality of life	Per capita postal and telecommunications volume
		The number of Internet users
	Environmental benefit	The proportion of days in which air quality reaches or exceeds the secondary level
		Comprehensive utilization of industrial solid waste
		Centralized treatment rate of urban sewage treatment plant

4. Conclusion

In view of the shortcomings of the evaluation index system of innovation ability of regional science and technology, based on the existing academic literature, this paper use social network analysis method to extract indicators and explain them step by step. Finally, this paper builds an optimized evaluation index system for innovation ability of regional science and technology in China, including 4 first-level indicators, 10 second-level indicators and 32 third-level indicators, hoping to more effectively evaluate innovation ability of regional science and technology.

The research mainly defines the evaluation index system for innovation ability of regional science and technology from the four dimensions of basis, investment, output and benefit. The output of science and technology innovation mainly includes direct output of scientific and technological activities and High-tech industrialization two indicators. In view of the dominant position of the enterprises in the innovation of regional science and technology, this paper combines enterprise technology innovation with the above two indicators as second-level indicators under the first-level indicator of science and technology output, which enriches the essence of the output of scientific and technological innovation. The third-level indicators include average annual wage of employed persons in scientific research and technology services. And this paper attempts to make a more practical explanation of environmental benefits from the perspective of "three wastes", which ensures the scientificity and clarity of the whole evaluation index system. In addition, the indexes are mutually exclusive, overcoming some cross-cutting problems of the existing evaluation index system, accurately analyzing the current status and major problems of innovation ability of regional science and technology, and making the evaluation results feedback more targeted. The evaluation of the index system will be more operable. This paper attempts to use the social network method to objectively construct a set of evaluation index system for innovation ability of regional science and technology from the perspective of comprehensive research and carry out the relevant description and analysis. However, the construction of the evaluation index system, may fail to properly show the regional characteristics of indicators. In fact, there are some differences or even greater differences in different regions. Therefore, when the evaluation index system is actually applied to regional assessment, it is also necessary to make appropriate adjustments according to the characteristics and differences of different regions. Of course, whether the evaluation index system is truly effective or not needs to be further explored and verified in combination with the actual evaluation so as to better improve the evaluation.

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About the authors:

1. SUN Xiaokun (1992-), female, Hebei, P.R. China, master graduate student, Research interest: the policy of science and technology.
2. SUN Qigui (1963-), male, Anhui, P.R. China, Ph.D., associate professor, Research interest: the theory and policy of innovation.