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Evaluating the Coordinated Development of Regional Innovation Ecosystem in China

Bin-Qing Cai [1], Xin-Huan Huang [2*]

[1] School of Management, Fujian University of Technology, Fuzhou 350118, CHINA

[2] School of Economics, Fujian Normal University, Fuzhou 350117, CHINA

[*] Corresponding author: xinhuanhsy@163.com

Abstract

According to the thought of system theory, regional innovation ecosystem consists of four subsystems: the subsystem of regional innovation resources, the subsystem of innovation resources flow, the subsystem of basic environment for innovation, the subsystem of policy environment for innovation. The evaluation index system is established to reflect the diversity of innovation agents, the flow of innovation resource, and the complexity of innovation environmental that highlighting the policy environment for innovation. Improved G1 method based on grey relational degree, the coordination degree model based on bull's-eye distance and the contribution algorithm of grey target are jointly applied to analyze coordinated development degree of innovation ecosystem for China's 30 provinces, autonomous regions and municipalities in 2016, and identify the key influencing factors of coordinated development. The results show that the coordinated development level of regional innovation ecosystem is not so high, and presents the obviously spatial pattern of east highest and west lowest. Nationwide, the subsystem of regional innovation resources is the most weak and unbalanced-development subsystem, the subsystem of innovation resources flow is the last but one subsystem. Talent resources, technology flow, fund flow, firm agglomeration condition, legal policy are the important influencing factors of coordination development.

Keywords: regional innovation ecosystem, coordinated development evaluation, contribution degree

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INTRODUCTION

Innovation paradigm has gone through three stages: the linear paradigm, innovation system and innovation ecosystem. With the success of Silicon Valley in United States, innovation system with characteristics of engineering and mechanization has gradually evolved into innovation ecosystem with organic and ecological characteristics. The members of the President's Council of Advisors on Science and Technology (PCAST) have identified the elements of innovation ecosystem are responsible for maintain USA global competitive advantages (PCAST 2004).Because most interactions in the process of technological progress occur at the regional level (Zou et al. 2016), nowadays more and more countries realize the importance of cultivating and building a well-functioning regional innovation ecosystem, and China is no exception. China is devoting herself to building an innovation-oriented country. Grasping the development status quo of regional innovation ecosystems is an important issue from both theoretical and practical standpoints for China, which is helpful for her to making reasonable policies to improve national innovation capability.

Regional innovation ecosystem consists of firms, colleges and universities, productive R&D centers, government, intermediary agencies, industry associations, economic, political and social environments (Birol et al. 2016, Chesbrough et al. 2006). The above elements work together in complex synergy by innovation resources flow, agent interaction and interdependence in a given geographical space (Hu et al. 2018). A history of innovation resources flow and agent interaction makes innovation ecosystem to develop as a regional differences, dynamic adaptability, partial balance and coordinated system (Liu 2010, Liu et al. 2015). What a well-functioning regional innovation ecosystem should be and how to measure it have become interesting issues. In order to identify whether regional innovation ecosystem is in the well-functioning state, some studies about regional innovation ecosystem assessment are carried out.

Firstly, suitability (Li et al. 2017, Zhou et al. 2008), health degree (Miao et al. 2008), performance and efficiency (Lou et al. 2009, Wan et al. 2016), competitiveness (Lu et al. 2016) are respectively used to measure whether regional innovation ecosystem is in

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the well-functioning state. Based on the thought of system theory, development is direction of system movement, and coordination is beneficial constraint and regulation of development. The well-functioning regional innovation ecosystem not only reaches a high level development of each subsystem, but also achieves coordinated development among subsystems. In view of this, innovation ecosystem can be divided into four subsystems: the subsystem of regional innovation resources, the subsystem of innovation resources flow, the subsystem of basic environment for innovation, the subsystem of policy environment for innovation. Development degree is used to measure the reaching level of development for an ecosystem or its subsystems. Coordination degree is used to measure consistency level of development process among subsystems. Coordinated development is integration of coordination and development, and coordinated development degree is used to describe comprehensive state of development level and coordination effect for regional innovation ecosystem (Huang et al. 2015).

Secondly, parts of evaluation indexes of innovation ecosystem are selected from that of innovation system, the indexes don't highlight the characteristics of innovation ecosystem. One of the noteworthy characteristics of regional innovation ecosystem is the diversity of innovation agents (Hannan et al. 1977). Firms, R&D institutions, colleges and universities are more involved in the previous evaluation index system, but the roles of market intermediary agencies, industry associations are less reflected. Next, the interaction between agents is another characteristic of regional innovation ecosystem. The previous evaluation indexes mainly show the static structure of ecosystem elements, and don't reflect the flow of innovation resources. However, innovation ecosystem paradigm puts more emphasis on the evolution of agent interaction behavior. Technology flow and fund flow are the key elements of innovation ecosystem. Innovation agents and external environment are integrated a unified whole by resource exchange among them (Chesbrough et al. 2014). The flow of resources should be fully taken into account in evaluation index system. Then, regional innovation ecosystem operates in a compound environment (Hu et al. 2018). Infrastructure environment and market demand are more reflected in the previous evaluation index system. However, policy environment is the most important factor that affects the operation of innovation ecosystem, but because it is difficult to collect data to measure it, it is less showed in the previous evaluation index system.

Thirdly, the methods such as entropy value method combined TOPSIS method (Sun, 2016), the principal component analysis (Luo et al. 2009), the multi-level fuzzy comprehensive evaluation method (Miao et al. 2008) are respectively applied to evaluate regional innovation ecosystem. However, the indexes used for evaluating coordinated development of regional innovation ecosystem are only the tip of the iceberg of all the indexes, with the remainder unknown ones lying in the dark corner. In most cases, these indexes only can cover a fraction of system information. Grey system theory is a new way to discover the inherent law of system with less data and poor information. Evaluation method for system coordinated development based on grey system theory and the contribution algorithm of grey target can be jointly applied to analyze coordinated development degree ant its key influencing factors of China's regional innovation ecosystem.

The remainder of this paper is structured as follows: coordinated development evaluation indexes system of regional innovation ecosystem is established in section 2. The evaluation index system has been innovatively extended. The indexes reflecting innovation resources flow are introduced in our evaluation indexes system. Especially, the indexes reflecting the roles of intermediary agencies and industry association in promoting the flow of innovation resources is selected into the index system. The subsystem of basic environment for innovation is comprehensively and systematically embodied by the elements: infrastructure conditions, agglomeration conditions, market demand, education foundation, and innovation atmosphere. More to the point, agglomeration conditions indexes are relatively rarely showed in the other relevant works. In addition, the indexes reflecting policy environment for innovation such as market policy, financial policy, and legal policy are added into the evaluation index system. Evaluation methods are briefly described in section 3.In section 4, improved G1 method based on grey relational degree, the coordination degree model based on bull's-eye distance and the contribution algorithm of grey target are jointly applied to analyze coordinated development degree of innovation ecosystem for China's 30 provinces, autonomous regions and municipalities in 2016, and identify the key influencing factors of their coordination development. The results are briefly concluded, and the policy proposals are put forward to promote sustainable development of regional innovation ecosystems in section 5.

Table 1. Evaluation index system

Subsystem	Subsystem Elements	Indexes	Weight
Regional innovation Resource	Talents	Full-time equivalent of R&D Personnel by region (man-year)	0.1086
		Full-time equivalent of R&D Personnel in Industrial Enterprises above Designated Size (man-year)	0.1095
		Full-time equivalent of R&D Personnel in R&D Institutions(man-year)	0.1220
		Full-time equivalent of R&D Personnel in Higher Education(man-year)	0.0978
	Funds	The R&D Expenditure Input Intensity by Region (%)	0.1080
		Intramural Expenditure on R&D by Government Funds (10 000yuan)	0.1217
		Intramural Expenditure on R&D by Self-raised Funds by Enterprises (10 000yuan)	0.1084
	Technology and Knowledge	Three Kinds of Domestic Patent Applications Granted (piece)	0.1082
		Chinese Scientific Papers Taken by Major Foreign Referencing System (piece)	0.1159
Innovation Resources Flow	Funds Flow	External Expenditure on R&D(10 000yuan)	0.1561
		Sales Revenue Proportion of New Products of Industrial Enterprise above Designated Size(%)	0.1314
	Technology Flow	Value of Contract Inflows to Domestic Technical Markets (10 000yuan)	0.1602
		Revenue from Transfer and Licensing of Patent Ownership in R&D Institutions and Higher Education (10 000yuan)	0.1686
		Value of Technology Contracts Imported (USD 10 000)	0.1558
	Role of intermediary agencies and industry associations	Market Intermediary Organization Service Conditions	0.1256
		Degree of Help From Industry Associations	0.1024
Basic Environment for Innovative	Infrastructure	The Rates of Internet Penetration (%)	0.0644
		Per Capita Capacity of Mobile Telephone Exchanges (household)	0.0693
		Length of Optical Cable Lines Per 10 000 Population (km)	0.0708
	Agglomeration conditions	Number of Enterprises of High-Technology Industrial Development Zone (unit)	0.1146
		Number of Total Resident Companies of Technology Business Incubators (unit)	0.1063
	Market demand	Per Capita Disposable Income of Households (yuan)	0.0846
		Total Retail Sales of Consumer Goods(100 million yuan)	0.0958
	Educational Foundation	Per Capita Educational Funds(10 000yuan)	0.1099
		Number of Higher Education Students Per 100 000 Population (person)	0.0773
	Innovation Atmosphere	Annual Funding for S&T Popularization (10 000yuan)	0.1073
		Visitors of S&T Museums (10 000 person-time)	0.0997
Policy Environment for Innovation	Market Policy	Market Allocation of Economic Resources	0.1631
		The extent of prices determined by the market	0.1582
		Reducing Local Protection in Commodity Markets	0.1581
	Financial Policy	Marketization of Financial Industry	0.1677
	Legal Policy	Safeguarding the Legal Environment of the Market	0.1710
		Intellectual Property Protection	0.1819

EVALUATION INDEX SYSTEM

The evaluation index system is established by referring to research results of some representative literature (Duan et al. 2017, Jiang et al. 2018) (**Table 1**). The evaluation index system fully reflects the diversity of innovation agents, the flow of innovation resource, and the complexity of innovation environmental that highlighting the policy environment for innovation.

EVALUATION METHOD

Improved G1 method based on grey relational degree (Huang et al. 2015) is applied to calculate the weights of subsystem indexes, which was helpful to scientifically measure subsystem development degree of regional innovation ecosystems. Coordination degree model based on bull's-eye distance (Huang et al. 2015) is used to calculate coordination level among subsystems. The contribution algorithm of grey target (Huang et al. 2013) is applied to identify the key influencing factors of coordination development. Due to space limitations, improved G1 method based on grey correlation degree and contribution algorithm of grey target is omitted here.

Coordination Degree Model based on Bull's-eye Distance

For evaluating coordinated development of regional innovation ecosystems, suppose that

$i \in I = \{1,2,\ldots,l\}$ stands for regional innovation ecosystem's subscript, and l stands for number of regional innovation ecosystem; $j \in J = \{1,2,\ldots,m\}$ stands for subsystem subscript, and m stands for number of subsystem; $k \in K = \{1,2,\ldots,n\}$ stands for index subscript, and n stands for number of index for each subsystem; x_{ijk} stands for dimensionless value of index k of subsystem j for regional innovation ecosystem i; w_{jk} stands for weight of index k of subsystem j; y_{ij} stands for development degree of

subsystem j for regional innovation ecosystem i; y_{ij} stands for ideal development degree of subsystem j for regional innovation ecosystem i; c_i stands for system coordination degree of regional innovation ecosystem i.

Then, development degree of subsystem j for regional innovation ecosystem i is expressed by

$$y_{ij} = \sum_{k=1}^{n} w_{jk} x_{ijk}, k = 1,2,\ldots,n, j = 1,2,\ldots,m, i = 1,2,\ldots,l \quad (1)$$

The bull's-eye distance (r_i) is used to measure the distance between ecosystem actual state and ideal coordination state for each subsystem of regional innovation ecosystem i. It can be expressed by

$$r_i = [(y_{i1} - y'_{i1})^2 + (y_{i2} - y'_{i2})^2 + \ldots + (y_{im} - y'_{im})^2]^{1/2}, i = 1,2,\ldots,l \quad (2)$$

The greater bull's-eye distance is, the more deflected from actual state to ideal coordination state is, the lower system coordination degree is. In accordance with representative meaning of other models' calculation result, coordination degree model based on bull's-eye distance is defined by formula (3).

$$c_i = \left(\sqrt{1 - \left(r_i / \left\lceil \max_{1 \le i \le l} r_i \right\rceil\right)}\right)^{\varphi}, i = 1,2,\ldots,l \quad (3)$$

where φ ($\varphi > 0$) is adjustment coefficient, $\left\lceil \max_{1 \le i \le l} r_i \right\rceil$ is the smallest integer greater than or equal to $\max_{1 \le i \le l} r_i$.

c_i is between 0 and 1. The greater its value is, the more coordinated the ecosystem is.

Coordination is in the consistency state among the subsystems. Ideal coordination state should be a state of consistent development for each subsystem. Therefore, the median of subsystem development degree is set as the value of an ideal coordination state. Ideal value of development degree, formula (1), and formula (2) are generated into formula (3), and let $\varphi = 1.8$, coordination degree model of China's regional innovation ecosystem is got.

Comprehensive Development Degree and Coordinated Development Degree

Comprehensive development degree (y_i) is calculated by the linear weight synthesis model. Suppose that each subsystem is equally important, their weights are equal. The algorithm is expressed by formula (4).

$$y_i = \frac{1}{m} \sum_{j=1}^{m} y_{ij}, i = 1,2,\ldots,l \quad (4)$$

Coordinated development degree (d_i) is calculated by the nonlinear weight synthesis model. Usually, Weights of comprehensive development degree and coordination degree are also equal. The algorithm is expressed by formula (5).

$$d_i = \sqrt{y_i c_i}, i = 1,2,\ldots,l \quad (5)$$

EVALUATION RESULTS

Data Sources

The innovative ecosystem of 30 provinces, autonomous regions and municipalities in China are taken as the evaluation objects. Tibet isn't included because some data can't be obtained. The data are acquired from China statistical yearbook 2017, China science and technology statistical yearbook 2017, marketization index of China's provinces: NERI Report 2016 (Wang et al. 2017). The improved G1 method based on grey relational degree is applied to calculate the weight of indexes (**Table 1**).

Comprehensive Development Degree

Comprehensive development degrees are distributed in the interval [0.1499, 0.6964] (**Table 2**).That of Beijing is highest, but its value is only 0.6964. That of Beijing, Guangdong and Jiangsu is more than 0.6. The average value is 0.3583. Therefore, comprehensive development degree is relatively low, and there is great room for improvement.

From the perspective of geographical distribution, the top eight provinces are all in the eastern region, and Hubei, Liaoning respectively rank 9th and 10th. Chongqing, Sichuan and Shaanxi in western region, Anhui, Hunan, Henan and Jiangxi in central region, Heilongjiang and Jilin in northeast region, Hebei in eastern region rank in the middle 10. The provinces ranking at the last 10 are mainly in the western region, except Shanxi in central region, Hainan in eastern region. The mean of eastern, northeastern, central and western regions respectively are 0.4995, 0.3247, 0.3216 and 0.2598.The comprehensive development degree of China's regional innovation ecosystem shows obvious geographical distribution features of east highest and west lowest.

Table 2. Comprehensive development degree

Region	Comprehensive Development Degree	Region	Comprehensive Development Degree	Region	Comprehensive Development Degree
Beijing	0.6964	Chongqing	0.3649	Guangxi	0.2776
Guangdong	0.6857	Anhui	0.3519	Shanxi	0.2604
Jiangsu	0.6247	Sichuan	0.3505	Hainan	0.2497
Shanghai	0.5810	Shaanxi	0.3447	Inner Mongolia	0.2457
Zhejiang	0.5749	Hunan	0.3355	Ningxia	0.2431
Shandong	0.4672	Henan	0.3264	Xinjiang	0.2280
Tianjin	0.4060	Hebei	0.3043	Gansu	0.2223
Fujian	0.4047	Heilongjiang	0.3040	Yunnan	0.2157
Hubei	0.3747	Jilin	0.3019	Guizhou	0.2153
Liaoning	0.3683	Jiangxi	0.2805	Qinghai	0.1499

Table 3. Development degree of subsystem in the four regions of China

Region / Subsystem	Eastern region	Northeast region	Central region	Western region	Nationwide
Regional Innovation Resource	0.3852	0.1483	0.1716	0.0982	0.2135
Innovation Resource Flow	0.4085	0.2146	0.2093	0.1314	0.2451
Innovation Basic Environment	0.4536	0.2878	0.2743	0.2773	0.3365
Innovation Policy Environment	0.7506	0.6483	0.6436	0.5323	0.6389

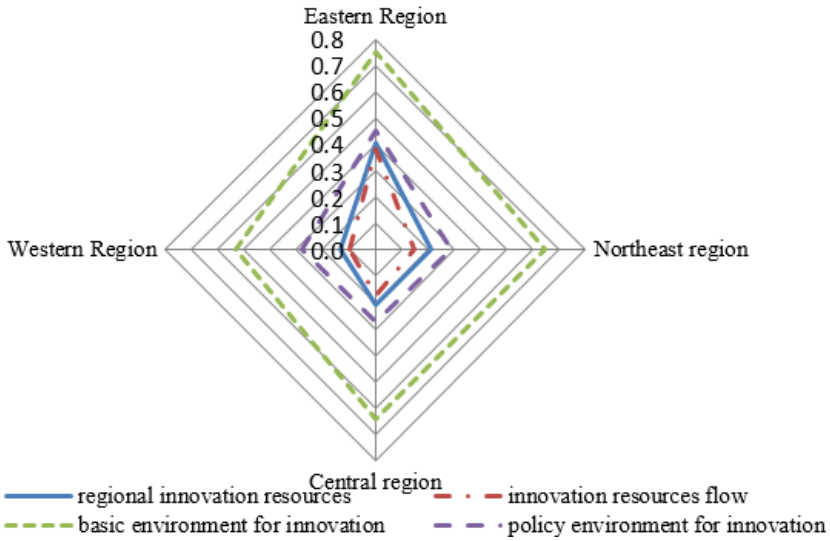

Fig. 1. Development degree of subsystem

Development Degree of Subsystem

According to the development degree of four subsystems in the four regions of China (**Table 3** and **Fig. 1**), the national mean of the subsystem of regional innovation resource is the smallest, but the standard deviation is the largest. The development degree in the eastern region is almost four times bigger than that in the western region. So the subsystem of regional innovation resource is the most weak and unbalance subsystem. In terms of talent resources, R&D personnel investment of R&D institutions is highly agglomerated in Beijing, Sichuan, Shaanxi. R&D personnel investment of enterprises in Guangdong, Zhejiang and Shandong are far ahead of other provinces. In terms of R&D expenditure, Beijing, Shanghai, Sichuan and Shaanxi are in the forefront of government fund in R&D expenditure. The R&D expenditure by enterprise fund in Guangdong, Jiangsu, Shandong and Zhejiang are far ahead of other provinces, and the R&D expenditure by enterprise fund in these four provinces is almost 50% of the national total.

The innovation resource flow subsystem is the last but one subsystem. The development degree in the eastern regions is much bigger than that of other regions. That in the western regions is also lowest. Excepting for Beijing, Shanghai, Jiangsu and Zhejiang, revenue from transfer and licensing of patent ownership, external expenditure on R&D are rather low.

For innovation basic environment subsystem, there is no big difference in the northeast, central and western

Table 4. Coordination degree

Region	Coordination Degree	Region	Coordination Degree	Region	Coordination Degree
Beijing	0.9269	Hunan	0.6879	Liaoning	0.6403
Guangdong	0.8028	Hebei	0.6812	Jilin	0.6397
Qinghai	0.7683	Shandong	0.6694	Guizhou	0.6362
Shanghai	0.7412	Gansu	0.6663	Tianjin	0.6331
Sichuan	0.7361	Anhui	0.6509	Hainan	0.6281
Shaanxi	0.7194	Heilongjiang	0.6502	Henan	0.6250
Xinjiang	0.7186	Chongqing	0.6492	Jiangxi	0.5829
Jiangsu	0.7180	Shanxi	0.6443	Fujian	0.5814
Hubei	0.7001	Zhejiang	0.6434	Inner Mongolia	0.5798
Yunnan	0.6940	Ningxia	0.6414	Guangxi	0.5775

Table 5. Coordinated development degree

Region	Coordinated development Degree	Region	Coordinated development Degree	Region	Coordinated development Degree
Beijing	0.8034	Chongqing	0.4867	Xinjiang	0.4048
Guangdong	0.7419	Liaoning	0.4856	Jiangxi	0.4044
Jiangsu	0.6697	Fujian	0.4851	Guangxi	0.4004
Shanghai	0.6562	Hunan	0.4804	Hainan	0.3960
Zhejiang	0.6082	Anhui	0.4786	Ningxia	0.3948
Shandong	0.5592	Hebei	0.4553	Yunnan	0.3869
Hubei	0.5122	Henan	0.4517	Gansu	0.3848
Sichuan	0.5080	Heilongjiang	0.4446	Inner Mongolia	0.3774
Tianjin	0.5070	Jilin	0.4395	Guizhou	0.3701
Shaanxi	0.4980	Shanxi	0.4096	Qinghai	0.3394

regions, but the national mean is not so high. Innovation basic environment subsystem of Beijing, Guangdong, Jiangsu, Shanghai and Zhejiang are in a good state. The national mean of innovation policy environment subsystem is relatively high.

Coordination Degree

The coordination degrees are distributed in [0.5775, 0.9269]. Beijing is in excellent coordination state, and Guangdong is in good coordination state. Seven provinces, such as Qinghai, Shanghai, Sichuan, Shaanxi, and so on, are in moderate coordination. 17 provinces, such as Yunnan, Hunan, Hebei and so on, are in mild coordination. Jiangxi, Fujian, Inner Mongolia and Guangxi are moderately imbalance (**Table 4**).

According to the spatial distribution of coordination degree, some provinces in the central and western regions are with the higher coordination degree, but some provinces in the eastern regions are lower. For example, Qinghai and Sichuan respectively rank at 3rd and 5th, and Fujian ranks at 27th. The mean of eastern region, northeast region, central region and western region are respectively 0.7025, 0.6434, 0.6485 and 0.6715. It is the highest in the eastern region, and lowest in the northeast region.

Coordinated Development Degree

According to evaluation value of coordinated development degree (**Table 5**), the provinces with the coordinated development degree greater than 0.5 are mainly distributed in the eastern region, excepting for Hubei and Sichuan. The provinces with coordinated development degree between 0.4 and 0.5 are distributed in various regions. The provinces with coordinated development degree below 0.4 are mainly in the western region, excepting for Hainan.

The mean of eastern region, northeast region, central region and western region are respectively 0.5882, 0.4566, 0.4561 and 0.4138. Therefore, the geographical distribution features is east highest and west lowest.

According to the OECD classification standards, the corresponding coordination states are defined as excellent coordination, good coordination, moderate coordination, mild coordination, low imbalance, moderate imbalance and serious imbalance, whose coordination degrees are respectively (0.9,1], (0.8,0.9], (0.7,0.8], (0.6,0.7], (0.5,0.6], (0.4,0.5], and [0,0.4]. The development states are defined as three types: well development, medium development and low development, whose development degrees are respectively distributed in the interval [0.4,0.7), [0.3,0.4) and [0.2,0.3). Based on comprehensive

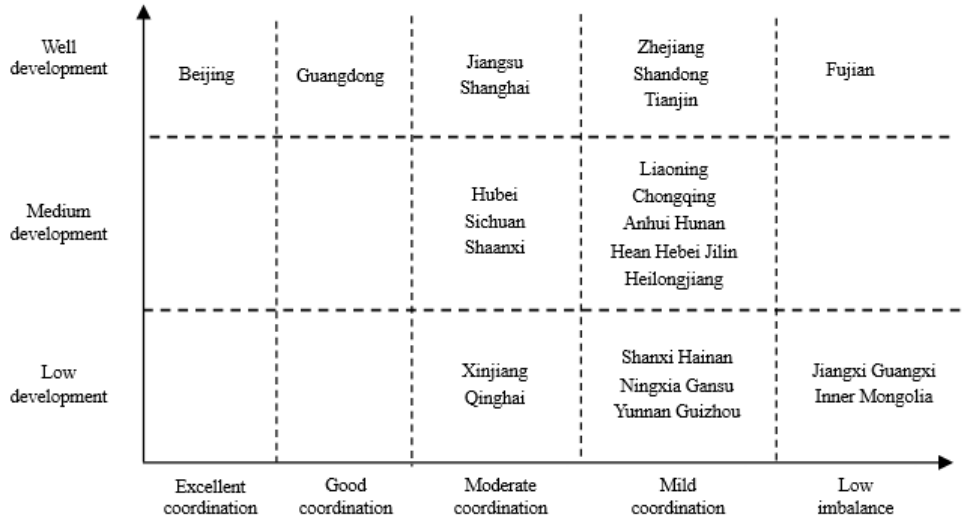

Fig. 2. Classification results with comprehensive development degree and coordination degree

Table 6. Contribution degree of evaluation indexes

Rank	Regional innovation resources	Contribution degree	Innovation resources flow	Contribution degree	Innovation basic environment	Contribution degree	Innovation policy environment	Contribution degree
1	Full-time equivalent of R&D Personnel in R&D Institutions	0.8664	Revenue from Transfer and Licensing of Patent Ownership in R&D Institutions and Higher Education	0.8751	Number of Enterprises of High-Technology Industrial Development Zone	0.1146	Intellectual Property Protection	0.8015
2	Intramural Expenditure on R&D by Government Funds	0.8644	Value of Contract Inflows to Domestic Technical Markets	0.8315	Per Capita Educational Funds	0.1099	Safeguarding the Legal Environment of the Market	0.5233
3	Chinese Scientific Papers Taken by Major Foreign Referencing System	0.8236	External Expenditure on R&D	0.8103	Annual Funding for S&T Popularization	0.1073	The extent of prices determined by the market	0.4537
4	Full-time equivalent of R&D Personnel in Industrial Enterprises above Designated Size	0.7780	Value of Technology Contracts Imported	0.8089	Number of Total Resident Companies of Technology Business Incubators	0.1063	Marketization of Financial Industry	0.4521
5	Full-time equivalent of R&D Personnel by Region	0.7715	Sales Revenue Proportion of New Products of Industrial Enterprise above Designated Size	0.6820	Visitors of S&T Museums	0.0997	Market Allocation of Economic Resources	0.4228

development degree and coordination degree, regional innovation ecosystems in various provinces are classified (**Fig. 2**).

Beijing ranks at the first in terms of coordinated development degree, who reaches a high development level, and its subsystems are in the excellent coordination state. There is inconsistent states between comprehensive development and coordination for some provinces, that is, high development level and low coordination level, or low development level and high coordination level. For example, innovation ecosystem of Fujian is in the state of high development level and low coordination level. Fujian's comprehensive development ranks at 8th, but its coordination degree only ranks at 27th. The reason is that innovation policy environment of Fujian ranks at 5th, but innovation resource only ranks at 15th. Particularly, R&D Personnel input of R&D Institutions is about a third of the national mean, and expenditure on R&D by government funds is about half of the national mean. Xinjiang and Qinghai are in the state of low development level and high coordination level. The comprehensive degrees of Xinjiang and Qinghai respectively rank at 26th and 30th, but their coordination degrees respectively rank at 7th and 3rd.

Contribution Degree of Evaluation Indexes

Contribution algorithm of grey target is applied to calculate the contribution degree of evaluation indexes of regional innovation ecosystem, which is to analyze how various indexes affect the coordinated development of regional innovation system (**Table 6**).

In the subsystem of regional innovation resources, the top 5 indexes of contribution degree are Full-time equivalent of R&D Personnel in R&D Institutions, Intramural Expenditure on R&D by Government Funds, Chinese Scientific Papers Taken by Major Foreign Referencing System, Full-time equivalent of R&D Personnel in Industrial Enterprises above Designated Size, Full-time equivalent of R&D Personnel by Region. Talent class indexes accounted for 3 places in the top 5 indexes. It indicates that talent resource is the most critical innovation resources.

In the subsystem of innovation resources flow, the indexes reflecting technology flow-Revenue from Transfer and Licensing of Patent Ownership in R&D Institutions and Higher Education, Value of Contract Inflows to Domestic Technical Markets, Value of Technology Contracts Imported - respectively rank at 1st, 3rd and 4th. The indexes reflecting fund flow-External Expenditure on R&D, Sales Revenue Proportion of New Products of Industrial Enterprise above Designated Size- respectively rank at 2nd, and 5th.

In the subsystem of basic environment for innovation, the indexes reflecting agglomeration conditions - Number of Enterprises of High-Technology Industrial Development Zone, Number of Total Resident Companies of Technology Business Incubators - respectively rank at 1st, and 4th. The indexes reflecting innovation atmosphere -Annual Funding for S&T Popularization, Visitors of S&T Museums- respectively rank at 3rd, and 5th. Per Capita Educational Funds ranks at the 2nd.

In the subsystem of policy environment for innovation, the indexes reflecting legal policy - Intellectual Property Protection, Safeguarding the Legal Environment of the Market - respectively rank at 1st, and 2nd. The indexes reflecting market policy- The extent of prices determined by the market, Market Allocation of Economic Resources - respectively rank at 3rd, and 5th. The index reflecting financial policy - Marketization of Financial Industry - ranks at 4th.

CONCLUSIONS

The well-functioning regional innovation ecosystem not only reaches a high level development of each subsystem, but also achieves coordinated development among subsystems. Relevant policy proposals are obtained based on the evaluation results to promote sustainable development of regional innovation ecosystem.

Firstly, comprehensive development degree and coordinated development degree of China's regional innovation ecosystem are not so high, and they have obvious regional distribution characteristics, presenting the spatial pattern of east highest and west lowest. The development level of the eastern regional innovation ecosystem is obviously higher than that of other regions. The coordination degree of China's regional innovation ecosystem is also not high, showing the spatial distribution characteristics of eastern highest and northeast lowest.

Secondly, parts of regional innovation ecosystems are in an inconsistent state between comprehensive development degree and coordination degree, that is, high development degree and low coordination degree, or low development degree and high coordination degree. It is necessary to promote the coordinated development among subsystems at a high level. Therefore, it is the basic way to enhance coordination level among subsystems on the basis of improving the development degree of weak subsystems.

Thirdly, the subsystem of regional innovation resource is the most weak and unbalance subsystem. The innovation resource flow subsystem is the last but one subsystem. The distribution of talents, funds, technology and knowledge is extremely uneven. Innovation resources are concentrated in eastern region, and the western region innovation resources input is rather low. Therefore, the flows of intra-regional and inter-regional innovation resource should be enhanced on the basis of increasing the input of all kinds of innovation resources. The regional innovation cooperation should be strengthened, and innovation resources should be flowed from the eastern region to other regions, especially to the western region. The evaluation scores of innovation basic environment and innovation policy environment is comparative even in the northeast region, central region and western region, but that of the east region is more higher than other three regions. Cultivating innovation basic environment and innovation policy environment is still an important mission for other three regions.

Fourthly, the key factors of each subsystem should be paid more attention to more effectively improve the development level of each subsystem. Talents resources are the most critical innovative resources. Technology flow and fund flow are the key elements in the subsystem of innovative resources flow. Enterprise agglomeration conditions, education basis and innovation atmosphere are the key elements in the

subsystem of basic environment for regional innovation. Legal policy is the most critical element in the subsystem of policy environment for regional innovation. Therefore, actively cultivating enterprise agglomeration conditions, increasing investment in education, and creating a good innovation atmosphere are conducive to promoting the basic environment of regional innovation. The intellectual property protection system and the legal system to maintain the market order should be further perfected in the scientific and reasonable way. In addition, the roles of intermediary agencies and industry association in promoting the flow of innovation resources, and the fundamental role of resources distribution by the market should be fully played to promote regional innovation ecosystems evolving into the coordinated development state.

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