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Spatial heterogeneity analysis of urban innovation efficiency in Shandong Province

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Abstract: *Regional innovation plays an important role in shaping new development momentum and is an important support for the construction of an innovative country. From the perspective of value chain, the two-stage input-output index system of urban innovation in Shandong Province was constructed, and the DEA-BCC model was used to evaluate the innovation efficiency of Shandong Province and other cities during 2013-2020. The findings are as follows: The innovation efficiency of the two stages of the province has great potential to improve, especially the economic transformation efficiency, and the pure technical efficiency is the key factor affecting the improvement of comprehensive innovation efficiency. The spatial heterogeneity of urban innovation efficiency is obvious. According to the research results, urban innovation can be divided into four types: efficient intensive type, high R&D type but low economic transformation, low R&D but high economic transformation type, and extensive and inefficient type. Finally, the paper puts forward the improvement path of urban innovation efficiency in Shandong Province.*

Keywords: *Shandong Province, Innovation efficiency, Value chain, heterogeneity*

1. Introduction

The report of the Party's 20th National Congress in 2022 proposed "we should thoroughly implement the strategy of innovation-driven development and comprehensively build a modern socialist country." The Central Economic Work Conference in 2023 stressed that scientific and technological innovation should lead the construction of a modern industrial system and develop new quality productivity. To form new quality productive forces, we must rely on science, technology and innovation. In recent years, Shandong Province has built a regional science and technology innovation system to accelerate the output and transformation of scientific and technological achievements to achieve the goal of building an innovative province. According to the "China Regional Innovation Capability Evaluation Report" from 2015 to 2022, Shandong Province has long been a leading region in innovation capability, and its innovation capability continues to maintain the sixth place in the country. There are some good examples of first 5 provinces and some other provinces with great ambition bebind. In the face of the leading edge whose advantages continue to expand and rapid catch-up provinces of great momentum, Shandong Province's innovation ability improves relatively slow, leading the challenge. Moreover, due to the differences in location, resource endowment and other factors, combined with the polarization effect of innovation resources in core cities, the spatial difference of urban innovation efficiency in Shandong Province is obvious, which restricts the improvement of the overall innovation capability of Shandong Province to a certain extent. Therefore, in-depth analysis of the heterogeneity of urban innovation efficiency in Shandong Province is of great practical significance for accelerating the formation of new quality productivity, enhancing new development momentum, and creating a new pattern of high-quality development led by innovation collaboration.

2. Literature review

Foreign scholars tend to use relevant indexes to evaluate regional innovation efficiency, such as the innovation index of the European Union, and use Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) to evaluate regional innovation performance through the input-output data of innovation factors. Wang (2007) used SFA method to analyze the efficiency of innovation research and development across countries[1]. Fare and Grosshpf (1997) used DEA model to evaluate and compare the technological innovation efficiency of different APEC member countries[2]. Faria, Ana Paula (2020) selected data from several European regions and applied SFA to prove that the interaction between regions has an important impact on regional innovation efficiency[3].

In the early stage, the evaluation of domestic innovation efficiency was carried out by using various statistical analysis methods on the basis of building an index system, while in the later stage, scholars tended to divide the innovation process into stages and use various models in DEA to measure regional innovation efficiency. The research objects mainly included provinces, domestic innovative pilot cities and specific industries. Earlier scholars such as Zhen Feng (2000) [4], Duan Lizhong (2003) [5] and Tang Qiong (2014) [6] used factor analysis, gray clustering analysis, entropy weight method and gray comprehensive evaluation method respectively to evaluate the innovation capability of major coastal provinces and cities and representative innovative cities. Later scholars such as Dai Ming (2011) [7], Liu Xiangyun (2020) [8] and Yuan Rong (2023) [9] used the DEA-CCR model, SFA stochastic frontier model and super-efficiency SBM model respectively to conduct empirical studies on the efficiency of science and technology innovation in national innovation pilot cities, Guangdong-Hong Kong-Macao Greater Bay Area, Yangtze River Delta and other regions. For the evaluation of industrial innovation efficiency, Yao Zhenghai et al. (2016) used the DEA-BCC model to evaluate the innovation efficiency of six sub-sectors of China's high-tech service industry[10]. Guo Benhai et al. (2023) used Bootstrap-DEA model to evaluate the innovation efficiency of high-tech manufacturing industry in various provinces of China driven by digital economy[11].

Most of the current studies are at the provincial level, innovation pilot cities and industrial levels, but there are few studies on the differentiation of innovation efficiency among cities in Shandong Province. In view of this, this paper draws on the existing research results and builds the input-output index system of urban innovation in Shandong Province from the perspective of innovation value chain. The DEA-BCC model is adopted to analyze and evaluate the spatial difference of innovation efficiency of various cities in the province, clarify the advantages and disadvantages of each city in regional innovation, explore the key constraints, and find the path to improve urban innovation efficiency.

3. Evaluation index system and evaluation method

3.1. Construction of evaluation index system

Regional innovation activity is a complex and interrelated multi-stage process. A complete regional innovation process first needs to invest technology research and development resources, convert them into research and development results, and reflect the creation process of technical value; Then, the relevant organizations with enterprises as the main body put the research and development results into production, manufacture new products, and successfully commercialize the research and development results, which is reflected in the transformation process of economic value. Therefore, starting from the value chain of innovation process, regional innovation activities are divided into the stage of scientific and technological research and development and the stage of economic transformation (see Figure 1). Among them, the stage of science and technology research and development is the front-end behavior and the only way of innovation activities in the whole region, which provides technical support for obtaining innovation economic benefits. At this stage, the input of various technological innovation elements is the starting point, and the R&D output of new technologies and new processes is the end point. The economic transformation stage is the final result of the whole region's innovation activities and the process of obtaining economic value. This stage takes the research and development results generated in the technology research and development stage as the starting point, creates new products and puts them into the market, and finally obtains economic benefits, promoting economic growth. Based on the theory of innovation value chain, this paper constructs an index system from the two stages of innovation, and evaluates the overall efficiency of innovation activities, scientific and technological research and development efficiency and economic transformation efficiency of Shandong Province and other cities.

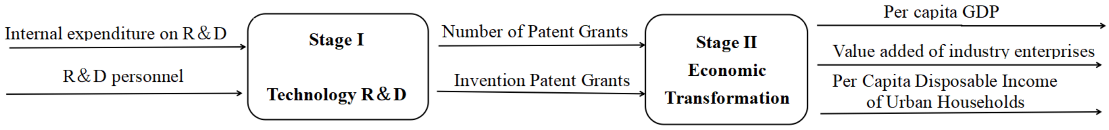

Figure 1 Two-stage process and indicator system for innovation

The first stage is the selection of input-output indicators in the R&D stage. In view of the fact that the output of science and technology is largely subject to the input of regional innovation resources, which includes the input of innovation manpower, material resources and financial resources, "internal expenditure of R&D funds" and "number of R&D personnel" are selected as the indicators of innovation investment in the first stage considering the availability of data. Scientific and technological output results are mainly based on papers, invention patents, utility model patents, and design patents. Starting from the commercial application value and data availability, "patent application authorization number" and "invention patent authorization number" are finally determined as the measurement indicators of regional science and technology output.

In the second stage, which is the economic transformation stage, the input index is the output index of the first stage. Based on the full consideration of the economic value of innovation and its contribution to regional economic and social development, the output index finally selects three indicators: "regional per capita GDP", "industrial added value" and "urban per capita disposable income".

3.2. Evaluation methods

In this paper, a two-stage DEA model is adopted to decompose the complex operation process of DUS, investigate the impact of each link on the overall efficiency, and deeply explore the internal structure and internal operation mechanism of the regional innovation system. It effectively avoids the traditional DEA model treating it as a "black box" when evaluating the regional innovation system.

By keeping the input or output of Decision Making Units (DMU) unchanged, the DEA method uses mathematical programming and statistical data to evaluate the relative effectiveness of decision making units with multiple inputs and outputs. Since this method has no specific requirements for data units, it can effectively judge the size of the input, the direction and degree of DMU adjustment, and the index weight is obtained by the specific value of DMU input and output, which has strong objectivity, so this method has become the main method for efficiency analysis at present. By sorting DMU, we can not only clearly judge the validity of each DMU, but also point out the invalidity degree of invalid DMU and the cause.[12]

BCC model is one of the main models in DEA method, which was proposed in 1984 by Banker, Charnes and Cooper on the basis of CCR model. Based on the assumption of variable returns to scale, the model divides Technical Efficiency (TE) into Pure Technical Efficiency (PTE) and Scale Efficiency (SE), and the relationship between the three is $TE=PTE*SE$. Because the model can determine whether the decision unit with multiple inputs and outputs has both "scale efficient" and "technology efficient", it is often used in DEA methods.

4. Evaluation of urban innovation efficiency in Shandong Province

4.1. Data source and processing

In this paper, Shandong Province and 16 prefecture-level cities were selected as independent decision-making units for data collection. Considering the impact of COVID-19 on data validity, the time span was selected from 2013 to 2020, and the relevant data were all from Shandong Statistical Yearbook and each city statistical yearbook.

There is a certain time lag between the periodicity of innovation activities and input-output. Referring to existing research references, the time delay of input-output at both stages is set at 2 years[13]. Therefore, in the first phase of evaluation, the input data is 2013-2016, and the output data is 2015-2018. In the second stage evaluation, the input data is the output data of the first stage, and the output data is from 2017 to 2020. In terms of regional scope, considering the adjustment of administrative divisions, that is, Laiwu City was merged into Jinan City in 2019, and in order to meet the needs of comparative analysis, 17 cities will be selected in the first stage of evaluation, and 16 cities will be selected in the second stage of evaluation.

4.2. First stage efficiency evaluation

The input-output data of the first stage was calculated by using the BCC model and DEAP2.1 software. The annual data of each city was taken as a unit, with a total of 17 cities and 68 units, and the relative efficiency values of each unit were obtained, as shown in Table 1.

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Table 1 Technical efficiency value of urban innovation technology R&D stage in Shandong Province

DMU	TE				PTE				SE			
	2013	2014	2015	2016	2013	2014	2015	2016	2013	2014	2015	2016
Jinan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Qingdao	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zibo	0.654	0.601	0.575	0.517	0.698	0.630	0.576	0.605	0.937	0.955	0.999	0.855
Zaozhuang	0.701	0.949	0.797	0.703	0.710	0.987	0.957	0.900	0.987	0.962	0.834	0.781
Dongying	0.479	0.607	0.505	0.531	0.564	0.629	0.598	0.661	0.849	0.965	0.844	0.803
Yantai	0.413	0.399	0.460	0.414	0.438	0.408	0.494	0.475	0.943	0.978	0.931	0.872
Weifang	0.704	0.804	0.787	0.714	0.904	0.856	0.787	0.715	0.779	0.940	1.000	1.000
Jining	0.836	0.884	0.929	0.810	0.978	0.977	0.930	0.818	0.855	0.905	0.999	0.991
Taian	0.356	0.381	0.418	0.409	0.383	0.395	0.419	0.432	0.931	0.964	0.998	0.947
Weihai	0.594	0.742	0.593	0.510	0.610	0.774	0.618	0.555	0.973	0.958	0.960	0.919
Rizhao	1.000	0.880	0.778	0.759	1.000	1.000	1.000	1.000	1.000	0.880	0.778	0.759
Laiwu	1.000	1.000	0.997	0.910	1.000	1.000	1.000	1.000	1.000	1.000	0.997	0.910
Linyi	0.635	0.653	0.660	0.580	0.689	0.653	0.685	0.650	0.922	0.999	0.965	0.892
Dezhou	0.670	0.770	0.742	0.688	0.710	0.791	0.771	0.732	0.945	0.973	0.963	0.939
Liaocheng	0.486	0.780	0.610	0.541	0.518	0.808	0.721	0.680	0.939	0.965	0.847	0.796
Binzhou	0.468	0.475	0.445	0.409	0.489	0.489	0.458	0.445	0.957	0.972	0.972	0.920
Heze	0.869	1.000	0.792	1.000	0.938	1.000	0.875	1.000	0.926	1.000	0.906	1.000
Average	0.698	0.760	0.711	0.676	0.743	0.788	0.758	0.745	0.938	0.966	0.941	0.905

Comprehensive technical efficiency is the product of pure technical efficiency and scale efficiency. It is a comprehensive measurement and evaluation of the efficiency of the utilization of the input resources of urban science and technology research and development, and reflects the maximum output level that a city can achieve when the input resources play a full role under the current technical conditions. If the input resources are fully utilized, DEA is effective, and the comprehensive technical efficiency value is 1. On the contrary, DEA is ineffective and the comprehensive technical efficiency value is lower than 1. If DEA is ineffective, the reasons for the ineffectiveness can be further explored from the decomposition of comprehensive technical efficiency. Pure technical efficiency is usually related to the system mechanism, management level and operation ability of the research area, which excludes the influence of scale factors. The scale efficiency only considers the impact of the scale of the evaluation object on the benefit, which is divided into three cases of increasing, decreasing and constant returns to scale.[14]

On the whole, the comprehensive technical efficiency of Shandong Province from 2013 to 2016 has a large room for improvement, and the annual average value is 0.698, 0.760, 0.711 and 0.676, respectively. The number of cities with a combined technological efficiency of 1 was 4 in 2013 and 2014, only 2 in 2015, and 3 in 2016.

From the regional point of view, there are great differences among cities in different years. The comprehensive technical efficiency value of Qingdao and Jinan has been stable at the level of 1 for four consecutive years, reflecting that the technology R&D efficiency of the two cities is relatively optimal during the study period, indicating that the input of existing scientific and technological resources has fully played its role, making the scientific and technological output reach the maximum, and the return to scale remains unchanged. The strong economic foundation or policy advantages have brought many advantages such as funds, talents, supporting environment, etc., making the two become the province's scientific and technological achievements output highland; Although the scale efficiency of Yantai, Tai 'an and Binzhou did not reach the optimal scale with an efficiency value of 1, the scale efficiency of the three cities was above 0.9 for four consecutive years, while the pure technical efficiency was low for four consecutive years, with a value between 0.3 and 0.4. It can be seen that the low comprehensive technical efficiency of the three cities was mainly influenced by the pure technical efficiency. Other non-efficient cities also generally exist the phenomenon of low pure technical efficiency. Therefore, the technological R&D innovation efficiency of most cities in Shandong Province is mainly limited by pure technical efficiency.

4.3. Second stage efficiency evaluation

The BCC model was used to evaluate the economic transformation efficiency of input-output of 16 cities in Shandong Province in the second stage of innovation, with a total of 68 evaluation units. With the help of DEAP2.1 software, the relative efficiency values of each city in the second stage of innovation

ISSN 2616-5783 Vol.7, Issue 1: 16-23, DOI: 10.25236/AJHSS.2024.070103

were obtained, as shown in Table 2.

Table 2 Comprehensive efficiency value of urban innovation economy transformation stage in Shandong Province

DMU	Comprehensive economic efficiency				Average
	2015	2016	2017	2018	
Jinan	0.200	0.196	0.203	0.234	0.208
Qingdao	0.271	0.244	0.238	0.210	0.241
Zibo	0.465	0.560	0.538	0.545	0.527
Zaozhuang	0.991	0.719	0.732	1.000	0.861
Dongying	1.000	1.000	1.000	1.000	1.000
Yantai	0.754	0.813	0.794	0.801	0.791
Weifang	0.288	0.299	0.348	0.337	0.318
Jining	0.471	0.493	0.505	0.535	0.501
Taian	0.675	0.657	0.529	0.595	0.614
Weihai	0.709	0.547	0.611	0.665	0.633
Rizhao	1.000	1.000	1.000	1.000	1.000
Laiwu	0.849	0.873	—	—	—
Linyi	0.539	0.533	0.552	0.624	0.562
Dezhou	0.615	0.622	0.744	0.848	0.707
Liaocheng	0.756	0.580	0.500	0.590	0.607
Binzhou	0.619	0.654	0.779	0.851	0.726
Heze	0.879	0.725	1.000	1.000	0.901
Average	0.652	0.619	0.630	0.677	0.645

As can be seen from Table 2, the economic transformation efficiency of most regions of the province is in a low range, and the effectiveness of nearly 75% of regions is lower than 0.8, indicating that in the future, the vast majority of cities in Shandong Province will have great room for improvement in promoting the transformation of scientific and technological achievements into economic benefits in the innovation process.

4.4. Spatial heterogeneity analysis of urban innovation efficiency

In order to compare and analyze the characteristics of innovation activities in various cities, cities with an efficiency value of [0.6-1] and cities with an efficiency value of [0-0.6] are classified as high-efficiency cities and low-efficiency cities by referring to the annual average of comprehensive efficiency in the two stages of urban innovation. In this way, a four-quadrant analysis diagram of the efficiency of the two stages of urban innovation in Shandong Province is constructed (see Figure 2). According to the regional innovation characteristics, all cities are divided into four different innovative cities: high-efficiency and intensive, high-R&D and low-transformation, low-R&D and high-transformation, and extensive type.

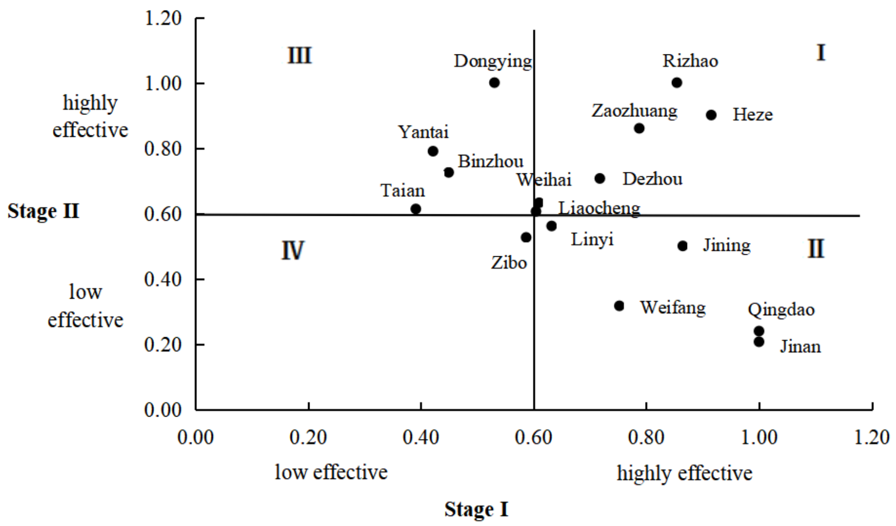

Figure 2 Analysis of innovation efficiency of regional innovation system in Shandong Province based on the second stage

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(1) Efficient and intensive innovative city

The cities in Quadrant I are Zaozhuang, Heze, Dezhou, Liaocheng, Rizhao and Weihai, which belong to efficient and intensive innovative cities. The research and development efficiency and economic transformation efficiency of these six cities are high, indicating that the innovation mechanism of these cities is relatively perfect, and the allocation of resources is relatively optimized. Rizhao's increasingly mature technology market operation shortens the distance between scientific and technological achievements and the market. The relatively low level of economic development in Zaozhuang, Heze, Dezhou and Liaocheng determines that their R&D investment is small, but their innovation system uses R&D resources more efficiently, so their output is at the forefront of production.

(2) Innovation city with high R&D and low economic transformation

The cities in the second quadrant include Jinan, Qingdao, Jining, Weifang and Linyi, which have relatively high efficiency in the stage of scientific and technological research and development, but low efficiency in the stage of economic transformation. It shows that the relevant mechanism of science and technology input works well and the output efficiency of science and technology input is high, but the scientific and technological innovation achievements are not well integrated with the local economic development, or there are bottlenecks, resulting in low economic transformation efficiency.

(3) Innovation city with low R&D and high economic transformation

The cities in the third quadrant include Yantai, Dongying, Binzhou and Tai 'an, which have low efficiency in the research and development stage, but relatively high efficiency in the economic transformation stage. On the one hand, the resources or industries in these areas have strong attraction to some scientific and technological achievements, thus improving the economic transformation efficiency of scientific and technological achievements in these areas. On the other hand, it reflects the strong dependence of such cities on external technological achievements, which ignores the efficiency of transforming technological innovation resources into technological achievements to a certain extent.

(4) Extensive innovative city

The only city in Quadrant IV is Zibo, with low innovation efficiency in both stages. In the first stage of innovation, during the study period, the average annual R&D expenditure of the city was 856,000 yuan, and the average annual investment of R&D personnel was 31,000, both of which were higher than the average level of the province. However, the high resource input may be due to the phenomenon of resource waste such as imperfect operation and management, resulting in a low output of scientific and technological achievements. At the same time, there may be blind investment in the economic transformation stage, resulting in the inefficiency or even idle of some projects and leading to low economic transformation efficiency.

5. Suggestions for improving urban innovation efficiency in Shandong Province

5.1. Strengthening the operation and management of innovation resources to improve the output level

The empirical analysis shows that most cities in Shandong Province have great room for improvement in both the R&D efficiency of the first stage and the economic transformation efficiency of the second stage in the process of regional innovation, and the limiting factor is the low pure technical efficiency, which reflects the efficiency of using initial innovation resources in each region. At the current stage, under the limited input of innovation resources, we should pay attention to the efficient and intensive use of resources and obtain higher output with less input as far as possible. Therefore, for cities with insufficient pure technical efficiency, emphasis should be placed on strengthening the training of high-quality management talents, developing efficient scientific research management models by improving the internal operation system and mechanism of cities, rationally allocating resources, and reducing the waste of existing input resources. At the same time, in the context of the "mass innovation strategy", we will fully learn from the management and operation experience of incubators in developed countries, explore operational models suitable for their own development, and improve the operation efficiency of the mass innovation space.

5.2. Adopting policies based on local conditions and cities to form differentiated regional innovative development models

From the comparative analysis of the two-stage efficiency of regional innovation, the key limiting factors of the improvement of innovation efficiency in each city are different, and the resulting improvement paths of innovation efficiency are also different. At the same time, due to the complexity of the actual situation in different regions and different stages and the differences in development potential among different cities, the innovation activities of each city have their own characteristics. Therefore, targeted and differentiated development strategies should be formulated for different cities.

The innovative cities with high R&D efficiency and low economic transformation efficiency, represented by Jinan and Qingdao, should focus on strengthening the connection between technological achievements and economic output and improving the marketization and industrialization level of technological achievements. Cities with low research and development efficiency and high economic transformation efficiency, while continuing to maintain a high economic transformation efficiency, increase research and development capital investment, improve the relevant incentive mechanism, improve the enthusiasm of scientific researchers, and promote the quality and quantity of research and development to reach a higher level. At the same time, in view of the strong dependence on external technology, such cities should strengthen the digestion and absorption of foreign technology and improve their re-innovation level. The extensive and inefficient innovative city should start from the system mechanism, management and operation level, scale efficiency, marketization level and other aspects, promote the coordinated development of all links, and fundamentally solve the problem of double inefficiency.

5.3. Deepening effective cooperation between government, industry, universities and research institutes

The regional innovation system is characterized by the diversity of innovation subjects. Governments, enterprises, universities and scientific research institutions jointly form the basis of the innovation system. Different innovation subjects have their own advantages and assume different innovation functions. The cooperative innovation between them can ensure the efficient operation of the regional innovation system and is the key to enhance the comprehensive strength of regional innovation. The government shall establish and improve relevant policies and laws to provide a guarantee and soft environment for innovation activities in the region, solve the problem of market failure, maintain the efficient operation of the innovation system, thus coordinating the relationship among various innovation entities, and promoting innovation interaction; As the core of regional innovation, enterprises play a direct role in promoting the marketization and industrialization of innovation achievements. Enterprises should actively cultivate and introduce talents and enhance their independent innovation ability. They should employ researchers from universities and scientific research institutions to solve technical problems encountered. Scientific and technological research and development centers can be established in universities and scientific research institutions to provide research and development funding support. At the same time, they should always pay attention to the latest scientific and technological research results of universities and scientific research institutions, and actively expand the new product market; Universities and scientific research institutions are the source of technological innovation, with strong innovation resources and innovation advantages. Through the delivery of high-quality innovative and entrepreneurial talents for enterprises, they can improve the quality of enterprise employees and management level, transfer the latest scientific and technological achievements to enterprises, to achieve the marketization and industrialization of the results. Innovation subjects cooperate with each other for development, mutual trust, mutual benefit, which can strengthen their contact with each other through information exchange and sharing, talent flow, knowledge sharing and other means, carrying out innovation activities through government, industry, university and research cooperation, and finally forming a market-oriented, industry-supported regional innovation system integrating government, industry, university and research.

5.4. Strengthening urban innovation linkage and promoting innovation integration

The improvement of the overall efficiency of innovation activities cannot be separated from the joint effect of the innovation efficiency of each part. On the whole, regional innovation activities in Shandong Province, no matter in the stage of scientific and technological research and development or economic transformation, have obvious differences in urban innovation efficiency. The lack of effective linkage mechanism among cities inhibits the improvement of the overall innovation efficiency of the province.

In order to fully enhance the regional collaborative innovation ability in Shandong Province, cities need to break administrative barriers, strengthen innovation cooperation between regions, optimize the spatial allocation of innovation factors, and establish and improve the long-term collaborative mechanism of regional innovation. Firstly, they need to strengthen cooperation and exchanges among scientific research institutions. Cross-regional research cooperation platforms and joint laboratories will be established to jointly carry out research projects and technological breakthroughs. A trading platform for scientific and technological achievements should be established to promote the sharing and transformation of scientific research achievements. Secondly, they need to further strengthen cross-regional collaboration in industrial innovation. They need to establish an urban industrial cooperation mechanism, promote industrial integration and complementarity, and explore new paths for coordinated industrial development. They also need to deepen the specialized division of labor, improve the coordination mechanism of innovation value chain, deploy innovation chain around the industrial chain, encourage enterprises to form industrial chain, and supply chain and value chain in the province, truly forming an integrated regional industrial innovation system. Thirdly, they need to establish the organization and management mechanism of the science and technology innovation community, jointly formulate and issue cross-regional plans, establish a regional common interest mechanism, ensure cooperation and coordination among all parties, thus promoting the construction of the science and technology innovation community.

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