Research on Evaluation and Spatial-Temporal Differentiation Laws of Regional Innovation Quality Based on Spatial Autocorrelation Model

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Abstract. The significant improvement of the regional integration development in Yangtze River Delta and researches on its innovation efficiency have received increasing attention. This paper conducted spatial autocorrelation analysis on the innovation efficiency scores of 41 regions in the Yangtze River Delta from 2012 to 2020. Through the measurement of innovation quality by DEA-Malmquist model, it is found that the differentiation degree of innovation quality level in the Yangtze River Delta region is continuously improving. Further research on these scores through spatial autocorrelation analysis has showed that the spatial distribution of innovation quality level in the Yangtze River Delta region has a significant spatial positive correlation. With high-value regions as the center, the innovation quality level of their surrounding regions is also relatively high; and the regions with the same spatial relationship show obvious contiguous distribution characteristics according to the results of local spatial autocorrelation analysis.

Keywords: Regional Development, Innovation Quality, Spatial Econometricss

1 Introduction

Innovation is the core driving force for a country's sustainable economic development, the key to shaping international competitive advantage, the first driving force for leading development, and the strategic support for building a modern economic system. In order to accelerate the construction of an innovative country and achieve the goal of providing powerful support for building China's strength in science and technology, product quality, aerospace, cyberspace and transport, and for building a digital China and a smart society, [1-5] innovation is an important means to solve the unbalanced and inadequate development. Economic development depends not only on quantity expansion, but also on quality improvement. Both in terms of quality and quantity, the speed needs to be accelerated and the standards need to be higher than before, which requires new management models, new thinking, and new technologies to drive.

At present, the Yangtze River Delta is one of the regions with active economic development, high degree of openness and strong innovation ability in China. The integrated development of the Yangtze River Delta has elevated to the status of national strategy, and its development direction and path have been defined from the top-level design [6-10]. It is conducive to discover and leverage the comparative advantages of "Jiangsu Province, Anhui Province, Zhejiang Province and Shanghai", coordinate and optimize the allocation of resources within the region, and promote high-quality coordinated regional development; it is helpful to explore the

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institutional system and policy supply mode of regional integration development, and play an exemplary role in regional integration development; and it is also beneficial for creating a diversified economic growth pole, promoting industrial transformation and upgrading, pushing forward supply-side reform, expanding high-level openness, and enhancing the resilience of national economic development.

2 Literature review

The regional difference of the Yangtze River Delta is one of the hot issues concerned by scholars at home and abroad. In order to improve the economic development speed, the mode of economic growth should be changed to innovation driven. As the most economically intensive and developed region [11-13], the Yangtze River Delta has remarkable research significance in innovation-driven development. A large number of studies have analyzed the spatial-temporal differentiation laws of regional innovation quality. Based on the research on innovation quality and efficiency, spatial interaction and spatial-temporal differentiation laws in the above literatures, the application of spatial econometrics to analyze regional innovation efficiency and spatial-temporal differentiation has become a hot spot in the current research on innovation quality. Some studies have shown that the level of innovation drive in some regions is not high, lower than the average level, which pulls down the innovation quality level in the whole Yangtze River Delta region. In this paper, the DEA-Malmquist model was applied to calculate and analyze the innovation ability of 41 cities in the Yangtze River Delta region, evaluating the development trend of innovation quality level in this region from horizontal and vertical comparison. Moreover, the spatial autocorrelation analysis was used to measure the overall spatial correlation degree of the Yangtze River Delta region, and to judge the specific clustering status of low or high innovation quality regions.

3 Indicator selection of innovation quality evaluation and construction of evaluation system

3.1 Sample Selection

In the context that the integration of the Yangtze River Delta has become a national strategy, it is reasonable to place higher expectations on the innovation quality in this region and expect it to make valuable exploration and exemplary contributions. The *Outline of the Integrated Regional Development of the Yangtze River Delta* released in December 2019 covered the whole territory of Shanghai, Jiangsu, Zhejiang and Anhui in the regional integration scope. In the studies of Chen et al. [14-16] and Ying Wu et al., the geographical scope of the Yangtze River Delta region was expanded to 41 cities.

3.2 Indicator selection

According to the requirements of DEA model for sample selection, 41 cities in the Yangtze River Delta region were selected as research objects, that is, decision-making units in this model. The input-output indicators were selected as follows from the two levels of input and output. Since the main components of innovation quality are mainly scientific research institutions,

enterprises and governments, this paper continued the logarithmic research method and subdivided the input indicators into the selection of capital variables and labor variables. Among them, the investment in social fixed assets was taken as a substitute indicator of capital stock. On this basis, following the principles of data comparability and uniformity, and taking into account the availability of data, 10 indicators were selected to build the evaluation index system of innovation quality level in the Yangtze River Delta region, as shown in Table 1.

Table 1. Innovation efficiency indicators and weight values.

First-Level Indicators	Second-Level Indicators	Indicator Description	Indicator Type
Innovation Inputs	R&D personnel input	R&D personnel of industrial enterprises above designated size	Positive
	R&D funds	R&D funds of industrial enterprises above designated size	Positive
	Funds for scientific research activities	Basic research expenditure of scientific research and development institutions	Positive
	Fixed assets at year-end	Total investment in fixed assets	Positive
	Number of high-tech enterprises	Number of high-tech industry enterprises	Positive
Innovation Outputs	Number of patent applications accepted	Number of domestic transcription applications accepted per capita	Positive
	Profit on new product sales	Sales revenue of new products in high-tech industries	Positive
	Gross industrial output value	GDP index	Positive
	Gross export value	Gross export value	Positive
	technical income	Information technology service revenue	Positive

3.3 Data source

Taking 41 cities in the Yangtze River Delta region as the research objects, and considering data availability and accuracy, the sample period was selected from 2012 to 2020. The data in this paper came from *China City Statistical Yearbook*, *China Statistical Yearbook on Science and Technology*, *China Statistics Yearbook on High Technology Industry* and municipal statistical yearbooks. Some missing annual data were supplemented by interpolation method.

4 Spatial and temporal pattern analysis of existing innovation quality in the Yangtze River Delta

4.1 Evaluation results of innovation quality in the Yangtze River Delta

The technological innovation efficiency scores and comprehensive scores of provinces and cities in the Yangtze River Delta region from 2012 to 2020 were obtained through calculation, and the results were shown in Table 2.

Table 2. Innovation quality level scores in the Yangtze River Delta Region from 2012 to 2020.

Cities	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	tfpch
Shanghai	1	1	1	1	1	1	1	1.327
Nanjing	0.922	0.854	0.812	0.864	0.915	0.954	1	1.08
Wuxi	0.914	0.924	0.935	0.944	0.811	0.805	0.731	0.981
Changzhou	0.802	0.812	0.875	0.867	0.984	0.857	0.984	0.964
Suzhou	0.815	0.845	0.865	0.992	0.945	0.994	1	0.911
Nantong	0.856	0.911	0.952	0.943	0.942	0.905	0.936	0.864
Yancheng	0.57	0.54	0.875	0.849	0.878	0.814	1	0.842
Yangzhou	0.791	0.302	0.743	0.852	0.871	0.905	0.950	0.854
Zhenjiang	0.807	0.333	0.453	0.687	0.851	0.824	1	0.864
Taizhou	0.684	0.456	0.584	0.799	0.745	0.901	0.735	0.835
Xuzhou	0.854	0.845	0.793	0.789	0.854	0.894	0.848	0.809
Lianyungang	0.753	0.593	0.856	0.746	0.906	0.882	1	0.854
Bozhou	0.345	0.879	0.845	0.754	0.741	0.856	0.81	0.741
Lu'an	0.875	0.969	0.845	0.875	0.789	0.875	0.857	1.011
Huangshan	0.24	0.26	0.45	0.56	0.58	0.67	0.445	0.754

As shown in Table 2, the overall pattern of innovation quality efficiency in the Yangtze River Delta region varies greatly. According to the data calculated from 2018 to 2020, there are 8 cities in the Yangtze River Delta with an innovation quality efficiency score of 1 or above, namely Shanghai, Nanjing, Suzhou, Yancheng, Zhenjiang, Lianyungang, Hangzhou and Wenzhou. There are 7 cities in this region with an innovation quality efficiency score of 0.9 or above, namely Changzhou, Nantong, Yangzhou, Ningbo, Wuhu, Huainan and Bengbu. The technological innovation quality level of the remaining 27 cities is less than 0.9, and this level of 7 cities among them, namely Suzhou, Huangshan, Zhoushan, Taizhou, Lishui, Anqing and Chizhou, is less than 0.6, ranking at the bottom of the 42 cities. It is found that the overall development level of the Yangtze River Delta region is low. The number of cities with a development level greater than 1 is relatively small, and the number of cities with a score of 0.7-0.5 is relatively large, indicating that the overall regional distribution is relatively unbalanced. That is to say, there is a big gap between the region with high innovation quality and the region with low development level.

4.2 Spatial autocorrelation analysis of existing innovation quality in the Yangtze River Delta

4.2.1 Global autocorrelation

The global spatial autocorrelation Moran index of innovation quality level in the Yangtze River Delta region from 2012 to 2020 was calculated by the Stata software. Table 3 shows the value of Moran index statistics in this region from 2012 to 2020 when k = 3.

Table 3. Moran Index Statistics in the Yangtze River Delta Region from 2012 to 2020.

Variables	I	E(I)	sd(I)	z	p-value*
y20122013	0.215	-0.025	0.102	2.356	0.009
y20132014	0.098	-0.025	0.102	1.087	0.124
y20142015	0.102	-0.025	0.102	1.246	0.106
y20152016	0.28	-0.025	0.101	3.016	0.001
y20162017	0.076	-0.025	0.101	0.999	0.159
y20172018	0.238	-0.025	0.101	2.608	0.005
y20182019	0.259	-0.025	0.102	2.787	0.003

It can be seen from Table 3 that the innovation quality level of the Yangtze River Delta region has no spatial correlation from 2013 to 2015 and from 2016 to 2017 at the significance level of 5%, but shows positive spatial correlation in 2012-2013, 2015-2016 and 2017-2020. This indicates a spatial clustering phenomenon in the distribution of innovation quality levels. Regions with high innovation quality are close to each other, while regions with low innovation quality are also close to each other.

Comparing the Moran index of 2012-2013 with that of 2018-2020, it is found that the Moran index of 2018-2020 is greater than that of 2012-2013, which indicates that the spatial positive correlation degree of innovation quality level in the Yangtze River Delta region is rising as a whole in 2018-2020. After 2018, the role of spatial factors in innovation quality growth has been strengthened. And Table 3 shows that Moran index statistics have basically remained stable after 2017.

4.3 Local autocorrelation

4.3.1 Moran scatter plots

The correlation analysis of local space in 2012-2013 and 2018-2020 was carried out respectively.

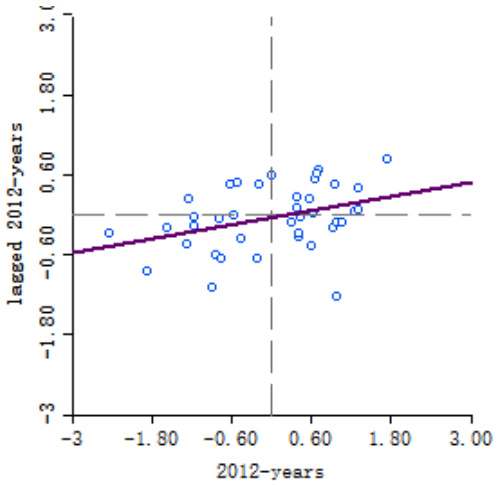

Fig. 1. Moran Scatter Plots from 2012 to 2013.

As shown in Figure 1, in 2012, cities located in the first quadrant included Shanghai, Nanjing, Nantong, Suzhou, Zhenjiang, Changzhou, Wuxi, Yangzhou, Lianyungang, Huai'an, Shaoxing and Ma'anshan, whose innovation quality was represented by areas with high innovation quality surrounded by areas with high innovation quality. Yancheng, Huzhou, Taizhou (Jiangsu), Taizhou (Zhejiang), Suzhou and Xuancheng were located in the second quadrant, and their innovation quality showed that areas with low innovation quality are surrounded by areas with high innovation quality. Cities located in the third quadrant included Lishui, Quzhou, Bengbu, Bozhou, Chuzhou, Wuhu, Tongling, Fuyang, Huaibei, Chizhou and Huangshan, whose innovation quality was characterized by low innovation quality areas surrounded by low innovation quality areas. In the fourth quadrant, there were Hangzhou, Suqian, Ningbo, Xuzhou,

Wenzhou, Jinhua, Anqing and Lu'an, whose innovation quality was represented by high innovation quality areas surrounded by low innovation quality areas.

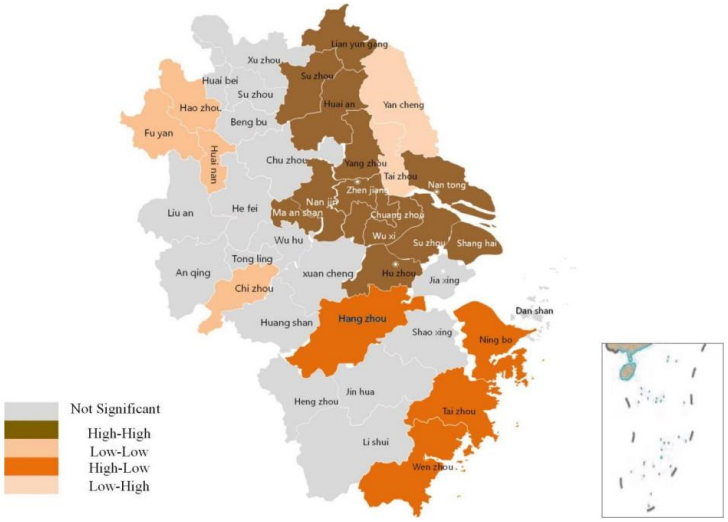

Fig. 2. LISA Cluster Map from 2012 to 2013.

As shown in Figure 2, in 2012, the contiguous area of Nanjing, Changzhou, Wuxi, Shanghai and other cities was in the High-High (H-H) area, indicating that the innovation quality level of the appellate cities was at the high value level, and their adjacent cities were also at the high value level. Cities like Shanghai and Nantong were located in the H-H area, while Yancheng was located in the Low-High (L-H) area, indicating that Yancheng' s innovation quality level was relatively low, but its adjacent cities were in a relatively high value level. Similarly, Taizhou (Jiangsu) was also in L-H area. The south of the Yangtze River Delta region was mainly in the High-Low (H-L) area, with Hangzhou and Wenzhou as typical cities. On the whole, L-H area was mainly distributed around H-H area. The whole northwest of the Yangtze River Delta was located in the Low-Low (L-L) area, indicating that it was at the low innovation quality level, and the relative development level between cities was also relatively low.

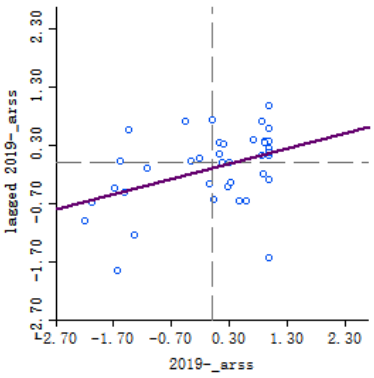

Fig. 3. Moran Scatter Plots from 2019 to 2020.

In 2020, as shown in Figure 3, the cities located in the first quadrant included Shanghai, Nanjing, Wuxi, Xuzhou, Changzhou, Suzhou, Nantong, Huai'an, Lianyungang, Yangzhou, Zhenjiang, Huzhou, Suqian and Shaoxing, whose innovation quality was represented by high innovation quality areas surrounded by high innovation quality areas. Yancheng, Taizhou (Zhejiang), Taizhou (Jiangsu), Chuzhou, Xuancheng and Ma'anshan were located in the second quadrant, and their innovation quality showed that areas with low innovation quality were surrounded by areas with high innovation quality. The cities located in the third quadrant were Bozhou, Quzhou, Bengbu, Fuyang, Lishui, Huainan, Anqing and Lu'an, whose innovation quality was represented by low innovation quality areas surrounded by low innovation quality areas. In the fourth quadrant, there were Ningbo, Wenzhou, Hangzhou, Jinhua, Hefei, Huangshan, Wuhu and Huaibei, whose innovation quality was characterized by areas with high innovation quality surrounded by areas with low innovation quality.

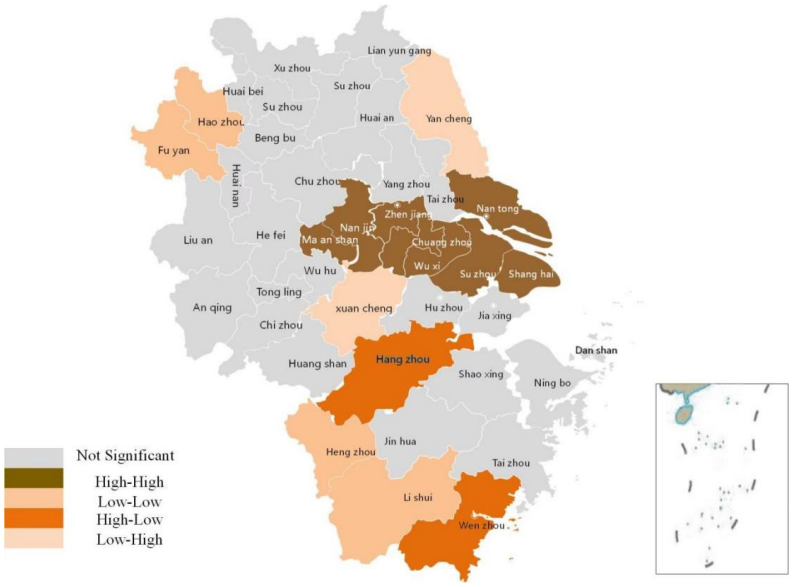

Fig. 4. LISA Cluster Map from 2018 to 2020.

As shown in Figure 4, in 2020, the contiguous area of Nanjing, Changzhou, Wuxi, Shanghai and other cities was in H-H area, indicating that the innovation quality level of the appellate cities was at the high value level, and their adjacent cities were also at the high value level. Compared with 2012, the high-value level area expanded to the north of the Yangtze River Delta, and there was a certain development in the both north and south. Cities like Shanghai and Nantong were located in the H-H area. Yancheng and Taizhou (Jiangsu) were located in the L-H area, indicating that their innovation quality level was relatively low, but their adjacent cities were at a relatively high level. The south of the Yangtze River Delta was mainly in the H-L area, with Hangzhou and Wenzhou as typical regions, expanded to Ningbo in 2020. On the whole, the L-H area was mainly distributed around the H-H area, and the H-H area extended further to the north to form a contiguous area. The northwest of the Yangtze River Delta was generally located in the L-L area, indicating that this contiguous region was at a low level of innovation quality, and the relative development level between cities was also relatively low.

The local spatial autocorrelation LISA maps reflected the spatial differentiation of innovation quality among different areas. Overall, the innovation quality level in the northeast of the Yangtze River Delta region had improved. Influenced by the eastern area, the innovation quality in the southeast had also improved. While, the innovation quality level in the northwest was lower than the former two, and its improvement was slow.

5 Conclusions and recommendations

5.1 Conclusions

As a manifestation of regional competition and development, the research on the innovation quality level in the Yangtze River Delta region can reflect its regional development status and the regional internal coordination.

According to the total factor production efficiency calculated by DEA-Malmquist model and the data from 2018 to 2020, there are 8 cities in the Yangtze River Delta region with the innovation quality efficiency score of 1 or above, namely Shanghai, Nanjing, Suzhou, Yancheng, Zhenjiang, Lianyungang, Hangzhou and Wenzhou. In this region, there are 7 cities with the innovation quality efficiency score reached 0.9 or above, namely Changzhou, Nantong, Yangzhou, Ningbo, Wuhu, Huaibei and Bengbu. The technological innovation quality level of the remaining 27 cities is less than 0.9, and this level of 7 cities among them, namely Suzhou, Huangshan, Zhoushan, Taizhou, Lishui, Anqing and Chizhou, is less than 0.6, ranking at the bottom of the 42 cities. It shows that the overall regional distribution is relatively unbalanced, and there is a big gap between areas with high innovation quality and areas with low development level.

As the regional integration of the Yangtze River Delta has expanded to Shanghai, Jiangsu, Zhejiang and Anhui, the horizontal scores of the three provinces and one city have been compared and analyzed to highlight the change trend of the overall region in time. The level of regional innovation quality in Shanghai had maintained an efficient development trend from 2012 to 2019. The overall level of Zhejiang Province remained at 0.8, but its development trend was unstable showing a fluctuating development status. After a sharp decline from 2012 to 2014, the innovation quality development in Jiangsu Province showed a good trend of high level and steady growth. In 2015, Jiangsu' s regional innovation quality level surpassed that of Zhejiang Province. Between 2016 and 2020, it had maintained a good development prospect, and its development status was gratifying.

According to horizontal and vertical comparative analysis, the differentiation degree of innovation quality in the Yangtze River Delta region had been constantly improving from 2012 to 2020. The east was the area with high innovation quality level; the northwest was the area with a relatively backward innovation quality level; the centre was the area with a rapid development of innovation quality; and the south was the area with full potential for innovation quality.

Through the spatial autocorrelation analysis and the comparison of the global Moran index from 2012 to 2020, it is found that the spatial distribution of innovation quality level in the Yangtze River Delta region has a significant spatial positive correlation. Cities with high innovation quality are close to each other, while cities with low innovation quality are also close to each

other. From 2018 to 2019, the spatial positive correlation degree of innovation quality level in the Yangtze River Delta region was on the rise as a whole, which shows that the spatial factor plays a significant role in the innovation quality growth.

5.2 Policy recommendations

(1) Forming a sound spatial pattern and research mechanism for innovation development

It is necessary to make good use of the excellent geographical and cultural resources in the Yangtze River Delta to speed up the construction of urban agglomerations in this region. It is needed to strengthen the internal cultural exchanges, economic ties, industrial ties and industrial collaborative development of cities in the Yangtze River Delta region, so as to accelerate the construction of innovative industrial chain to give full play to the comparative advantages of various cities, construct a good innovative social atmosphere, promote the internal resource circulation within cities in the Yangtze River Delta, and form a benign double cycle to play the cluster benefits.

It is ought to improve the talent circulation mechanism to promote the reasonable, effective and efficient circulation of talent resources in urban agglomerations. To form a good closed loop for talents, we should actively cultivate regional innovative talents, and strengthen the attraction of talents from other regions. This requires strengthening mutual trust and assistance, and internal exchanges of talents within urban agglomerations, to form a good talent attraction system. The society should strengthen cultural publicity and form an atmosphere of respecting knowledge and talents. Meanwhile, it is also necessary to form high-end industrial chains with complete systems and diverse types to increase the impetus for the reasonable flow of talents.

It is suggested to form a complete industrial mechanism and give full play to the advantages of industrial agglomeration. To form a more distinct industrial spatial pattern within the Yangtze River Delta region, it is necessary to promote the spatial concentration of regional innovation industries, increase economic investment, talent input and policy support for innovation industrial parks, and strengthen the talent attraction outside the region. At the same time, the Yangtze River Delta should actively carry out industrial adjustment and accelerate the elimination of backward production capacity, to achieve the industrial development to the upstream industrial chain, and further improve the development quality and efficiency. In addition, it is also needed to actively play the guiding role of consumption in the industry, make full use of the high-level consumption power in the Yangtze River Delta, and actively promote the supply side reform of the industry, to achieve the dynamic balance of the industrial structure and gradually form a distinctive industrial space pattern outside .

(2) Standardizing the intellectual property protection system and accelerating the system innovation

It is recommended to establish a property rights protection system with complete systems and strict measures. The Yangtze River Delta region should actively respond to the government's call to accelerate the improvement of the social legal system, to ensure that there are laws to follow and all laws must be followed. At the same time, the most strict legal mechanism should be used to improve the property rights protection system and respect knowledge. In response to the call of the "14th Five-Year Plan", it is necessary to improve the property rights protection system in new fields and new formats such as big data, artificial intelligence and gene

technology, strengthen the intellectual property protection system of the whole industrial chain, vigorously implement intellectual property protection, strive to build a benchmark city for intellectual property, and promote the legalization, institutionalization and systematization of intellectual property protection.

It is needed to accelerate institutional innovation and create a good social environment for innovation. We should accelerate the innovation of talent system and keep the dynamic adjustment of talent system innovation in combination with the domestic and international situation. In order to deal with the relationship between the government and the market, the government should actively play a leading role in talent system innovation, strengthen the top-level design and macro guidance, continue to deepen the reform of talent system and mechanism, and constantly improve the laws and regulations and support system of talent governance. Meanwhile, the market should also play a decisive role in resource allocation, constantly improve the mechanisms of price, supply and competition, promote the reasonable, orderly and efficient circulation of human resources, and provide necessary talent support for innovation and creation.

(3) Improving the foreign capital utilization way and strengthening the technology introduction

It is suggested to improve the way of foreign investment utilization and actively attract foreign investment. We should make use of innovations in the ways of foreign capital introduction, foreign investment and cooperation, constantly improve the ways of foreign capital utilization, actively seize the opportunity of the in-depth development of economic globalization, accelerate the circulation of international capital, promote the cross-border optimization of production factors, and enable the allocation of production factors at a higher level. It is ought to actively support foreign capital to cooperate with Chinese enterprises and scientific research institutions, better play the spillover effect of technology sharing, technology research and talent exchange, and innovate the ways and means of foreign capital utilization, so that international capital can better serve Chinese enterprises and scientific research institutions. It is also needed to constantly optimize the soft environment to provide a good social environment for scientific and technological innovation .

It is important to strengthen the introduction of foreign advanced technology and actively integrate the world civilization achievements. We should introduce the advanced technology needed by the industry development, and strengthen the harmonious linkage with colleges and universities, to cultivate our own high-tech talents. More importantly, it is necessary to transform the imported technologies into Chinese localization, and actively apply these technologies to our industry, so as to give full play to the function of the market and fully promote the internal flow of talents in the industry.

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