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Procedia Computer Science 221 (2023) 338–345

Procedia Computer Science

www.elsevier.com/locate/procedia

10th International Conference on Information Technology and Quantitative Management

Research on the Measurement of Innovation Efficiency in National High-tech Zones: Based on the Comparison of Three Urban Agglomerations in China

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Abstract

The high-quality development of national high-tech zones is a matter of great concern for both the government and scholars as it serves as an important base for realizing scientific and technological innovation and industrialization of achievements. This paper constructs a conceptual model of the national high-tech zone innovation system by breaking it down into two subsystems: the innovation R&D subsystem and the innovation incubation subsystem. Through the use of a two-phase Data Envelopment Analysis (DEA) model, the innovation efficiency of each subsystem is measured for the 42 national high-tech zones in Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta urban agglomerations. The research conclusion indicates that the majority of the high-tech zones in China are high in both research and development (R&D) efficiency and achievement conversion rate, indicating generally high overall innovation efficiency. However, there is a gap between the three urban agglomerations in terms of innovation resources and transformation environment, with Beijing-Tianjin-Hebei High-tech Zone having low transformation efficiency, and some areas of Yangtze River Delta and Pearl River Delta having low efficiency in technology R&D. Furthermore, the study finds that the innovation modes and paths of high-tech zones within urban agglomerations are quite different in the process of coordinated development of innovation. Therefore, the paper proposes two innovative development paths: the endogenous growth path and the exogenous driving path. The research results provide a tool for more objective evaluation of the innovation efficiency of national high-tech zones in different urban agglomerations in China, and provide a decision-making basis for different regions to implement corresponding innovative development paths.

Keywords: National high-tech zones ; Innovation efficiency ; Two-stage DEA model

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10.1016/j.procs.2023.07.046

1. Introduction

The report presented at the 20th CPC National Congress underscored the importance of accelerating the establishment of a new development pattern which enables innovation-driven development strategy and high-quality economic growth. Considering that national high-tech zones represent the core of China's active economy, harbor a substantial number of innovation resources, are home to rapidly growing high-tech industries, and act as an essential foundation for realizing technological innovation and industrialization of achievements[1], it is vital for them to actively integrate into the new development pattern of double circulation and the national regional coordinated development strategy. Furthermore, they must take on the crucial responsibility of building innovation-driven demonstration zones, high-quality development pioneer zones, and enhancing regional innovation capabilities. In 2021, state-level high-tech zone enterprises' R&D investments should account for half of the total R&D investments made by companies in China. Nevertheless, in the stage of high-quality development, it is essential to focus on not only investing in innovation elements but also boosting innovation efficiency[2]. The innovation efficiency has important influence on the optimal allocation of innovation resources in the zone as well as on the overall regional innovation growth.

Currently, certain high-tech zones are experiencing shortages in scientific and educational resources, exhibiting weaknesses in resource absorption capacity, possessing low industrial science and technology content, and lacking innovation and entrepreneurial atmosphere. Regrettably, these factors put them in a passive position with regard to regional coordinated development. In light of this situation, it is important, in the context of the new development pattern, to urgently explore strategies that enhance innovation efficiency in the process of innovative coordinated development. Therefore, this study objectively evaluates the innovation efficiency of national high-tech zones in different urban agglomerations through the two-stage DEA model, and deeply analyzes the innovation process of each high-tech zone, which has important practical significance for the reasonable allocation of innovation resources, the improvement of innovation efficiency of national high-tech zones and the creation of new growth poles for the coordinated development of various regions.

2. Literature review

Research has demonstrated that robust regional growth plays a critical role in the advancement of a nation's economy and its scientific and technological achievements [3,4]. In recent years, high-tech zones have garnered natable scholarly attention as the central position for regional coordinated innovation and development. Of note, the focus on "innovation efficiency of high-tech zones" and "innovation systems of high-tech zones" has shown a marked increase [5,6]. Innovation efficiency has been widely researched and measured across multiple levels and subjects. Notably, at the national level, scholars have examined the innovation output and regional disparities within the EU region. These findings offer valuable insights into the efficacy of innovative processes and their impact on various sectors [7]. Several scholars have conducted an assessment and scrutinized the regional efficacy of innovation in Portugal, China, and other nations [8,9]; Scholars have expressed interest in several urban agglomerations within the country, including but not limited to Silicon Valley, Gothenburg [10], Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta [11,12]. Measurement and analysis of innovation efficiency is conducted, and corresponding remedial actions are proposed.

The technical efficiency measurement methods of high-tech zones include parametric method and nonparametric method. The parametric method is based on the classical DEA model, and the nonparametric method mainly adopts the stochastic frontier analysis method [8]. In the selection of the final output index of high-tech zones, scholars mostly use GDP, technology income, patent authorization, export earnings, sales income and so on. Although many scholars try to grasp how to improve the efficiency of regional innovation in theory, few scholars pay attention to the differences of technological innovation development models between urban agglomerations. Furthermore, despite numerous scholarly attempts to investigate the advancement trajectory of regional innovation, there remains a dearth of investigation into the "black box" of innovation ecosystem, particularly concerning the stages of promotion for innovation efficiency in national high-tech zones.

3. Method

3.1 Research methods

Data Envelopment Analysis, also known as DEA method, is an efficiency evaluation method, which was first put forward by A.Charnes et al in 1978. Following its introduction to China by scholar Wei Quan-ling in 1988, the DEA method underwent further development and refinement in the region. Subsequently, this study embraced the Non-linear centralized model as its preferred approach.

3.2 Model

In accordance with the regional innovation system framework proposed by Cooke (2002), the structure of regional innovation system is mainly consists of two subsystems, namely, the knowledge application and development subsystem and the knowledge generation and diffusion subsystem. Using this framework, this current study dissects the innovation system of a high-tech zone and identifies its innovation R&D subsystem and innovation incubation subsystem. To evaluate the efficiency of this system, a two-stage DEA model is established based on the high-tech zone production system. The non-linear centralized model is selected for this purpose, and its overall comprehensive efficiency, technology R&D efficiency, and achievement transformation efficiency, are examined using the Dearun software. A detailed illustration of the model can be found in Figure 1 below.

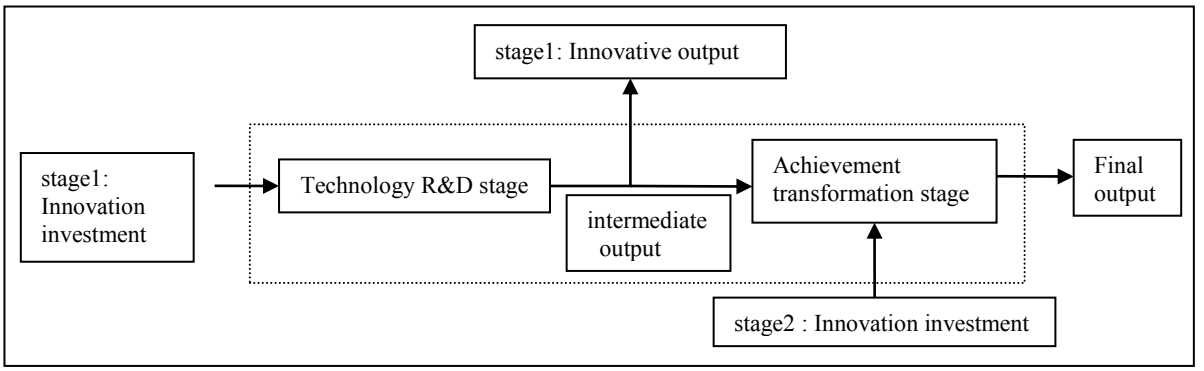

Figure 1 Complex Chain Production System in High-tech Zone

This study has developed a measurement index system to evaluate the two-stage innovation system within a high-tech zone in conjunction with relevant research and data availability.

Technology R&D stage:

Innovation investment: innovation capital investment is characterized by R&D funds; Innovative human capital is represented by R&D personnel. Innovative output: economic results are characterized by technical income; The output of innovative knowledge is represented by important intellectual property rights and standard quantity, which is intermediate output.

Achievement transformation stage:

Innovation investment: innovation capital investment is characterized by employees at the end of the year; Innovative manpower input is represented by year-end assets. Final output: characterized by total operating income, total industrial output value and export earnings.

3.3 Variables and data sets

For this particular research, the decision-making units were comprised of 42 high-tech zones hailing from the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta regions. The input-output index data of these high-tech zones from 2018 to 2020 were collected for analysis. Prior to conducting the efficiency analysis, steps were taken to eliminate the potential impact of dimensional differences in the original data by standardizing the data of each year. The sources of data for this study were drawn from reputable channels, including the China Science

and Technology Statistical Yearbook, the China Torch Statistical Yearbook, the Ministry of Science and Technology's official website, and the official websites of relevant high-tech zones.

4. Empirical research

4.1. Empirical results analysis

According to the DEA model constructed above, the results of the innovation efficiency in two stages are shown in Table 1.

Table 1 The innovation efficiency in two stages

City cluster	Hi-tech zone	Technology R&D efficiency	Efficiency of achievement transformation	Overall efficiency
Beijing-Tianjin-Hebei	Beijing Zhongguancun	0.970	0.796	0.772
	Tianjin Binhai	1.000	0.679	0.679
	Shijiazhuang	0.880	0.712	0.626
	Tangshan	1.000	0.783	0.783
	Baoding	0.850	0.761	0.647
	Chengteh	0.990	0.796	0.789
	Yanjiao	0.990	0.796	0.788
Yangtze River Delta	Zhangjiang Shanghai	0.870	1.000	0.870
	Zizhu Shanghai	0.990	0.817	0.809
	Nanjing	0.700	1.000	0.700
	Wuxi	0.900	1.000	0.900
	Xuzhou	0.990	0.807	0.799
	Changzhou	0.980	0.758	0.743
	Suzhou	0.910	1.000	0.910
	Nantong	0.970	0.862	0.837
	lianyungang	0.910	0.788	0.717
	Huaian	0.960	0.784	0.753
	Yancheng	0.990	0.755	0.747
	Yangzhou	0.950	0.765	0.726
	Zhenjiang	1.000	0.740	0.740
	Taizhou	0.960	0.787	0.756
	Suqian	0.950	0.777	0.738
	Hangzhou	1.000	0.790	0.790
	Ningbo	0.850	0.860	0.731
	Jiaxing	0.940	0.760	0.714
	Shaoxing	0.990	0.753	0.746
	Quzhou	0.930	0.767	0.713
	Hefei	0.900	0.915	0.824
	Wuhu	0.920	0.756	0.696
	Bengbu	0.910	0.774	0.705

	Huainan	0.980	0.794	0.778
	Cihu in Ma'anshan	0.950	0.852	0.809
	Tongling Shizishan	0.960	0.822	0.789
Pearl River Delta	Guangzhou	0.890	0.855	0.761
	Shenzhen	0.860	0.919	0.790
	Zhuhai	0.990	0.738	0.731
	Foshan	0.960	0.875	0.840
	Jiangmen	0.940	0.745	0.700
	Zhaoqing	0.930	0.755	0.702
	Huizhou	0.850	0.825	0.701
	Dongguan	0.850	1.000	0.850
	Zhongshan	1.000	0.759	0.759
Average value		0.936	0.816	0.761

Furthermore, the average innovation efficiency of the three urban agglomerations is calculated separately, as shown in Table 2.

Based on the comparison of empirical data, it has been observed that the technology R&D efficiency in Beijing-Tianjin-Hebei is relatively high, while the efficiency of achievement transformation is comparatively low. Conversely, the Yangtze River Delta and Pearl River Delta follow an opposite trend. Considering the innovation input data of the three urban agglomerations, the Pearl River Delta exhibits the highest level of innovation input, followed by Beijing-Tianjin-Hebei, and the Yangtze River Delta. However, the Pearl River Delta also showcases a high level of investment in innovation factors and low efficiency of technology R&D, which may indicate redundancy and resource wastage. In the future, it is advisable for the Pearl River Delta to reduce investment in innovation and focus on elevating the efficiency of technology R&D. On the other hand, the low innovation input rate and technology R&D efficiency in the Yangtze River Delta can be tackled by increasing the innovation input to enhance their technical proficiency. Beijing-Tianjin-Hebei can simultaneously improve the achievement transformation rate by collaborating with neighboring innovation achievers while maintaining an eco-friendly innovation system.

Table 2 The average innovation efficiency in two stage

City cluster	Technology R&D efficiency	Efficiency of achievement transformation	Overall efficiency
Beijing-Tianjin-Hebei	0.954	0.760	0.726
Yangtze River Delta	0.937	0.819	0.771
Pearl River Delta	0.919	0.830	0.759

From the value of technology R&D efficiency, the overall technology R&D efficiency is relatively high, with an average annual efficiency of 0.936. Five high-tech zones, namely Tianjin Binhai, Tangshan, Zhenjiang, Hangzhou, Zhongshan, show an efficiency of 1.000. The average R&D efficiency of Beijing-Tianjin-Hebei is the highest among them, and the Nanjing High-tech Zone is the lowest. Notably, high-tech zones such as Shijiazhuang, Baoding, Nanjing, Ningbo, Huizhou, and Dongguan exhibit significantly lower R&D efficiency compared to the overall average (0.936). This is attributed to factor like that Nanjing High-tech Zone has more investment in human capital, less investment in innovation capital, and uneven allocation of innovation resources. Shijiazhuang, Baoding, Ningbo, Huizhou and Dongguan have more serious problems such as weak innovation resource base and insufficient technology accumulation. Therefore, how to increase output with a certain input or reduce input with a certain output has become an urgent task.

From the value of achievement transformation efficiency, the overall achievement transformation efficiency is 0.816, which is generally lower than the overall technology R&D efficiency. Of the five high-tech zones that yield

effective results transformation, Zhangjiang, Nanjing, Wuxi, Suzhou, and Dongguan stand out. The Beijing-Tianjin-Hebei is the only urban agglomeration with an efficiency score lower than the overall average. This suggests that Beijing-Tianjin-Hebei has underperformed in the transformation of achievements; in other words, the combination of technology and economy in the region is low. Furthermore, the transformation efficiency of seven high-tech zones in Beijing-Tianjin-and Hebei is also lower than the overall average, hinting that the comprehensive transformation capacity of these zones demands further progress. Significantly, the transformation efficiency of achievements in Tianjin and Hebei High-tech Zones is notably inadequate, with Shijiazhuang High-tech Zone exhibiting the lowest performance. This points to considerable scope for development in improving the transformation ability of scientific and technological achievements in Hebei High-tech Zone.

From the overall comprehensive efficiency value, the mean value across the three urban agglomerations stands at 0.761. It is evident that all three urban agglomerations require an upgrade, with Beijing-Tianjin-Hebei lagging behind as the least efficient. Furthermore, the research discovered that certain developed cities are overrated in terms of their technological innovation capabilities. It is important to note that a high level of technological innovation does not necessarily equate to high efficiency. For instance, the Shenzhen High-tech Zone has been touted as a model case, but upon further investigation, its technology R&D efficiency was found to be lacking. This finding provides evidence that there may be superfluous resources in this region.

It should be noted that the technological R&D efficiency in Zhangjiang, Shanghai may be suboptimal, but its transformation efficiency is particularly notable, attributed to its geographical advantage within the Yangtze River Delta economic zone. By capitalizing on its unique position, Zhangjiang is able to effectively introduce and absorb technological R&D achievements, as well as industrialize scientific and technological breakthroughs within the Delta. Consequently, its overall comprehensive efficiency is commendable. This demonstrates useful management insights for driving innovation and development in other high-tech zones. Specifically, where independent innovation may be challenging, improving science and technology transformation ability can enhance overall comprehensive innovation competitiveness.

4.2. Further analysis

This study endeavors to identify path for enhancing the innovation efficiency of national high-tech zones. It does so by classifying the R&D efficiency, as well as the efficacy of achievement transformation, into three distinct types across 42 high-tech zones. The findings are then presented in the form of a matrix that facilitates the analysis of technological innovation modes within three urban agglomerations. A detailed account of the outcomes is available in Table 3.

Table 3 Matrix of Innovation Models of three urban agglomerations

	High technology R&D efficiency	Medium Efficiency of technology R&D	Low technology R&D efficiency
High achievement transformation efficiency	Zhongguancun, Zizhu Shanghai, Nantong, Foshan, Chengde, Yanjiao, Cihu Maanshan, Tongling Shizishan, Xuzhou.	Suzhou, Wuxi, Hefei	Dongguan, Huizhou, Nanjing, Shanghai Zhangjiang, Shenzhen, Ningbo , Guangzhou
Medium Efficiency of achievement transformation	Hangzhou, Huainan, Taizhou, Huaian, Tangshan, Suqian, Yangzhou, Zhongshan, Changzhou, Yancheng,Shaoxing.	Lianyungang, Bengbu, Quzhou, Jiaxing, Wuhu , Zhaoqing	Baoding
Low achievement transformation efficiency	Zhenjiang, Tianjin Binhai, Zhuhai	Jiangmen	Shijiazhuang

According to Table 3, through a comparative analysis, there exists a significant disparity amongst national high-tech zones, and collaborative innovation remains a prominent challenge. The Beijing-Tianjin-Hebei region offers an illustrative example, wherein Zhongguancun, Chengde, and Yanjiao operate within the high-R&D and high-conversion quadrant, with Tangshan also performing well in this regard. Conversely, Tianjin Binhai exhibits high

efficiency in technology R&D, but poor efficiency in achievement transformation, resulting in lower overall innovation efficiency. Baoding and Shijiazhuang, on the other hand, demonstrate suboptimal technology R&D, and achievement transformation efficiency, indicating ample scope for improvement. Consequently, bridging the internal gap between technological innovation output and economic performance of high-tech zones is a pressing concern that requires attention during the process of collaborative innovation development.

This study holds that addressing the gap within national high-tech zones calls for two strategies: enhancing the efficacy of technology R&D, and streamlining the efficacy of achievement transformation. The self-sufficiency of high-tech zones largely impacts the efficacy of technology R&D, while the efficiency of achievement transformation is influenced by both the technological transformation aptitude and the industrialization of external technological innovation accomplishments in high-tech zones. As a result, this paper presents two avenues for the innovation and growth of national high-tech zones: endogenous growth path and exogenous driving paths.

The endogenous growth path pertains to the advancement through the enhancement of their comprehensive capability to innovate, particularly in terms of independent innovation ability and internal achievement transformation ability. This path's realization can be based on each high-tech zone's existing industrial base within urban agglomerations. A robust management system should also be established and improved, while recognizing the vital role of the government, enterprises, universities, research institutions, and financial organizations in the high-tech zone development process. Creating a favorable environment for innovation and entrepreneurship is crucial in attracting key institutions to establish research institutions within the local high-tech zone. Providing excellent welfare benefits to allure domestic and foreign high-tech talents to work in the area is also vital. Strengthening the collaboration between enterprises and research institutes and improving the Industry-University-Research cooperation level can genuinely unleash the scientific research institutions' potential as a "source of innovation."

The exogenous drive path is an innovative approach that leverages external scientific and technological advancements to drive local industrialization. To effectively pursue this path, it is imperative for each high-tech zone to prioritize the platform role of high-tech zones and establish a conducive innovation incubation environment for technological achievements. The integrated development strategy presents a rare opportunity for high-tech zones to integrate into developed regions. The exogenous drive path prioritizes external scientific and technological advancements followed by internal industrialization, necessitating a clear source of innovation. Regions such as Beijing and Shanghai possess numerous innovative resources, which are crucial for high-tech zones in proximity to these areas to undertake scientific and technological advancements. Based on regional functional orientation, high-tech zones can speed up the integration of technological achievements, information technology, scientific and technological talents, market and industry. This will enable high-tech zones to transform location advantages into development advantages. While there may be some disparity among high-tech zones in these urban agglomerations, they have the benefit of geographical advantages and the foundation to undertake scientific and technological advancements, thereby achieving internal transformation.

Compared to high-tech zones such as Shanghai and Beijing, high-tech zones with low innovation efficiency face challenges in advancing overall independent innovation ability and in accumulating innovative resources and attracting new talent. Therefore, enhancing the development of a results transformation incubation mechanism proves to be a wise alternative in the absence of an independent innovation R&D mechanism. Specifically, we can engage in cooperative R&D projects with nearby high-tech enterprises, scientific research institutions, and universities to foster sharing and exchange of technology, information, and talents, thus strengthening innovative resources in high-tech zones and laying a strong foundation for independent innovation capability improvement. Alongside this, it is crucial to foster an innovation incubation environment and augment the achievement transformation mechanism, importing scientific and technological breakthroughs from adjacent areas to industrialize them in local high-tech zones. Such measures will bolster the achievements transformation and comprehensive innovation ability.

5. Conclusion and future research

Following the aforementioned research, the findings indicate that the majority of high-tech zones located in the three prominent urban agglomerations exhibit exceptional R&D efficiency and conversion rates. However, it was noted that the efficiency of achievement conversion within the Beijing-Tianjin-Hebei high-tech zone is

comparatively low, and the R&D performance within certain areas of the Yangtze River Delta and Pearl River Delta is suboptimal. This suggests the existence of a gap in innovation resources and achievement transformation in high-tech zones within urban agglomerations. Furthermore, it was observed that the innovation strategies and routes employed within high-tech zones in urban agglomerations vary significantly. Therefore, this study proposes two innovative development paths for national high-tech zones: the first is an endogenous growth path, where high-tech zones must establish tailored scientific research platforms, foster innovative R&D environments, and strengthen independent innovation capabilities; the second is an exogenous drive path, whereby high-tech zones should expedite the alignment of achievements, optimize achievement incubation environments, and enhance achievement transformation abilities.

Based on the findings of this study, it would be advisable to further discuss whether R&D capital investment or R&D manpower investment has a greater effect on innovation efficiency. This will enable us to develop more targeted measures to enhance innovation efficiency.

Acknowledgements

The Hebei Provincial Department of Education Humanities & Social Science Research Key Project (topic # ZD202304 “Research on the evolution mechanism and realization path of deep integration of industry, university and research in Beijing-Tianjin-Hebei”), the Hebei Provincial Social Science Development Research Key Project (topic # 20210101010 “Scientific and technological innovation to promote regional high-quality development research”) supported this research.

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