Academic Journal of Business & Management
ISSN 2616-5902 Vol. 6, Issue 7: 122-128, DOI: 10.25236/AJBM.2024.060717

Evaluation of Urban Innovation Efficiency in Shandong Province Based on DEA-Malmquist Model

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Abstract: *From the perspective of the value chain, innovation activities are divided into the technology R&D stage and the technology transformation stage. The input-output index system of urban innovation in Shandong Province is constructed. The overall and city-specific innovation efficiency of Shandong Province is evaluated by calculating the DEA-Malmquist index, using the panel data of the years 2013-2020 as a sample. It is found that at the overall level, the innovation efficiency M index of Shandong province has slightly decreased, and the technology R&D stage is mainly affected by EFF and TECH, while the technology transformation stage is mainly affected by TECH. At the regional level, the trend of innovation efficiency varies significantly between cities, with different constraints. Based on the conclusions of the study, recommendations for improving the urban innovation efficiency in Shandong Province are proposed.*

Keywords: *value chain; innovation efficiency; Shandong Province; DEA-Malmquist Index*

1. Introduction

Scientific and technological innovation is the source of productivity, and innovation capacity is the main embodiment of a country's core competitiveness. A new round of global scientific and technological revolution and industrial revolution is accelerating, and the world competition pattern will face re-adjustment. In order to seek competitive advantages, many countries have positioned innovation as the core strategy of the country. In the new era, China has changed the traditional extensive development mode, and its economic growth relies more on the the quality of human capital and technological progress. The report of the 20th National Congress of the Communist Party of China in 2022 proposed that "innovation is the first driving force" and "insist on the central position of innovation in the overall situation of China's modernization and construction. To develop new quality productivity, science and technology innovation is the core driving force. The in-depth implementation of the innovation-driven development strategy has become the core task of China's economic development and reform at present. According to the "Report on the Evaluation of China's Regional Innovation Capacity", Shandong Province has consistently ranked 6th nationally in terms of innovation capacity from 2015 to 2020, and is among the leading regions. However, In the face of provinces that continue to expand their lead and catch up rapidly, Shandong Province has been relatively slow to improve its innovation capacity. Therefore, it is of great practical significance to explore in depth the development trend and constraints of regional innovation capacity in Shandong Province, which is important for realizing the new pattern of high-quality development led by innovation as soon as possible.

2. Literature review

The innovation value chain theory provides a new research perspective for assessing innovation efficiency. Regarding the theoretical connotation of the innovation value chain, Hansen and Birkinshaw first proposed innovation as a continuous process divided into three phases: idea generation, transformation, and diffusion in their paper "The Innovation Value Chain"[1]. Roper et al. argue that the innovation value chain is a cyclical process of knowledge acquisition, transformation and utilization[2]. Domestically, Yu Yongze and Liu Dayong believe that technological innovation is a multi-stage, multi-factor value chain transfer process from innovative factor inputs to innovative product outputs[3]. According to Li Munan and Huang Fen, the innovation value chain is a concept derived from the traditional industrial value chain theory, and innovation is the process of value added and value chain formation[4]. From the innovation value chain theory, Yang Jian and Xia Huiliang used a three-stage DEA model including the stochastic frontier analysis method to evaluate the efficiency of science and technology innovation in national high-tech zones in central China and the Yangtze River Delta region[5]. Liu Shufeng et al. divided the innovation process into the knowledge condensation stage and the market transformation stage, and used the network DEA-SBM model to analyse the total innovation efficiency and the dynamics of the two-stage efficiency evolution and its causes in each province in China[6]. Based on the three-stage perspective of innovation, Fan Decheng and Wu Xiaolin used the network NSBM model to calculate the green technology innovation efficiency of Chinese industry and the efficiency values of the three stages[7].

The results of research on value chain theory and regional innovation efficiency strengthen the foundation of this study. Current evaluations of regional innovation efficiency are mostly static, while the dynamic evaluation reflects the evolution process of regional innovation capacity more realistically. DEA-Malmquist model is a dynamic evaluation method. Moreover, by reviewing the literature, there are few studies on regional innovation efficiency in Shandong Province from the value chain perspective. Therefore, based on the perspective of innovation value chain, the authors construct a regional innovation input-output index system in Shandong Province, and adopt the DEA-Malmquist index methodology to analyse the sources of motivation and constraints of urban innovation in terms of changes in the Total Factor Productivity (TFP) index and its decomposition index.

3. Indicator system and evaluation method

3.1. Construction of evaluation index system

Innovation is a systematic process of technological transformation based on the creation of knowledge, which in turn contributes to regional economic growth. Previous research has often treated the innovation process as a "black box", ignoring its internal structure and operating mechanisms. In reality, the innovation process presents obvious multi-stage and value chain transfer characteristics. By dividing the innovation process into stages, it is possible to effectively distinguish whether low innovation capacity is due to insufficient knowledge production capacity or limited market absorption capacity. Based on the innovation value chain perspective, the authors divide the innovation process into two stages: technology R＆D and technology transformation, and evaluate the efficiency of regional innovation in Shandong Province as a whole and in each sub-stage by constructing a chain linkage network DEA model based on variable returns to scale.

According to the principles of scientificity, comparability, dynamic guidance and accessibility, and following the theory of regional innovation, the evaluation index system of regional innovation system is constructed in two stages (see Figure 1). The first stage analyses the efficiency of scientific and technological outputs, in which the input indicators are selected as "internal expenditure on R&D" and "number of R&D personnel", and the output indicators are selected as "number of patent grants" and "invention Patent Grants". The second stage analyses the efficiency of technological transformation, in which the input indicators are the output indicators of the first stage, and the output indicators are chosen to be closely related to the economic benefits of innovation, such as "per capita GDP", "value added of industry enterprises", and "per capita disposable income of urban households".

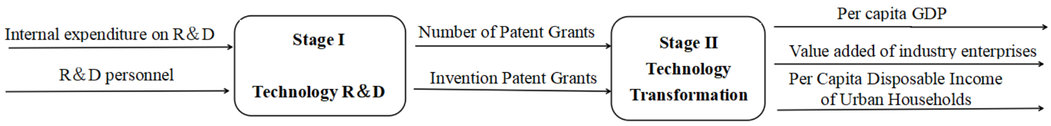

Figure 1: Two-stage process and indicator system for innovation

3.2. Evaluation method

In this study, the DEA-Malmquist productivity index method is used to evaluate the innovation efficiency of cities in Shandong Province and analyse the dynamic change of efficiency. The DEA-Malmquist model combines the DEA theory with the M index to evaluate the regional innovation efficiency by calculating the TFP. For any evaluation module, the index is decomposed into two parts, one for changes in technical efficiency over time and one for changes in the technology itself.[8-10]

The change in productivity from period t to t+1, ie:

ISSN 2616-5902 Vol. 6, Issue 7: 122-128, DOI: 10.25236/AJBM.2024.060717

$$M(x_{t+1}, y_{t+1}; x_t, y_t) = \frac{D_{t+1}(x_{t+1}, y_{t+1})}{D_t(x_t, y_t)} \times \left(\frac{D_t(x_{t+1}, y_{t+1})}{D_{t+1}(x_{t+1}, y_{t+1})} \times \frac{D_t(x_t, y_t)}{D_{t+1}(x_t, y_t)} \right)^{\frac{1}{2}}$$

$$EFF = \frac{D_{t+1}(x_{t+1}, y_{t+1})}{D_t(x_t, y_t)}, TECH = \left(\frac{D_t(x_{t+1}, y_{t+1})}{D_{t+1}(x_{t+1}, y_{t+1})} \times \frac{D_t(x_t, y_t)}{D_{t+1}(x_t, y_t)} \right)^{\frac{1}{2}}$$

Where EFF stands for technical efficiency change and TECH stands for Technical change.

EFF can be further decomposed into pure technical efficiency change (PEFF) and scale efficiency change (SE), viz:

$$EFF = PEFF \times SE$$

$$PEFF = \frac{D_{t+1}^{VRS}(x_{t+1}, y_{t+1})}{D_t^{VRS}(x_t, y_t)}, SE = \frac{D_{t+1}^{CRS}(x_{t+1}, y_{t+1})}{D_{t+1}^{VRS}(x_{t+1}, y_{t+1})} \times \frac{D_t^{VRS}(x_t, y_t)}{D_t^{CRS}(x_t, y_t)}$$

Combining the above processes, the M index is finally decomposed as:

$$M(TFP) = EFF \times TECH = PEFF \times SE \times TECH$$

M>1, indicating an increase in productivity; M=1, indicating no change in productivity; M<1, indicating a decrease in productivity. TECH>1, indicating technological progress; TECH=1, indicating no change in technology; TECH<1, indicating technological decline. EFF>1, indicating an increase in EFF; EFF=1, indicating no change in EFF; EFF<1, indicating a decrease in EFF.

3.3. Data sources and processing

16 cities in Shandong Province are used as the evaluation unit for the period 2013-2020, and the data are obtained from the Shandong Statistical Yearbook and each city's statistical yearbook. Due to the cyclical nature of innovation activities and the time lag between inputs and outputs, the inputs and outputs of the two phases are delayed by 2 years, drawing on the approach of Guan Jiancheng and Liu Shunzhong (2003)[11]. In the first phase of the evaluation, the input data are for 2013-2016 and the output data are for 2015-2018; in the second phase of the evaluation, the input data are the output data from the first phase and the output data are for 2017-2020. In terms of regional scope, taking into account the administrative division adjustment, i.e., the merger of Laiwu City into Jinan City in 2019, and for the purpose of comparative analyses, 17 cities were selected for the first phase , and 16 cities were selected for the second phase.

4. Empirical analysis

4.1. Analysis of technical output efficiency in stage I

Based on the input orientation, the M-index of technical output efficiency of cities in Shandong Province was calculated using DEAP2.l software, and the corresponding results were obtained.

At the overall level, Table 1 reflects the trend of technical output efficiency and related indicators in Shandong Province from 2013 to 2016.

Table 1: M-index of technical output efficiency in Shandong Province from 2013 to 2016

Year	EFF	TECH	PEFF	SE	M-index
2013—2014	1.096	0.846	1.063	1.031	0.928
2014—2015	0.940	0.968	0.967	0.972	0.910
2015—2016	0.944	1.249	0.982	0.961	1.179
Average	0.991	1.008	1.003	0.988	0.998

It can be seen that during this period, the average of M-index for the province as a whole is 0.998, which is close to 1. This indicates that the overall level of technological R&D efficiency in Shandong Province has remained basically unchanged. From the decomposition of the M-index, although TECH rose by 0.8 per cent, EFF fell by 0.9 per cent due to the influence of SE, which resulted a weak

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improvement in the efficiency of technological R&D in Shandong Province.

At the regional level, table 2 reflects the average of technical output efficiency in each city. During the study period, there were nine cities with an M-index greater than 1, accounting for 53 per cent of the province, indicating that the EFF of these cities was on an upward trend. The rest of the cities have an M-index of less than 1, showing a decreasing trend in EFF. Technological innovation productivity varies widely between cities. According to the M-value, cities are classified into three levels, where the thresholds are M-index = l (dotted line) and M-index = l.05 (solid line), see Figure 2.

Table 2: M-index of technical output efficiency for cities in Shandong Province

City	EFF	TECH	PEFF	SE	M-index
Jinan	1.000	0.981	1.000	1.000	0.981
Qingdao	1.000	1.070	1.000	1.000	1.070
Zibo	0.925	1.024	0.953	0.97	0.947
Zaozhuang	1.001	1.008	1.082	0.925	1.009
Dongying	1.035	1.016	1.054	0.982	1.052
Yantai	1.001	1.084	1.028	0.974	1.085
Weifang	1.005	1.017	0.925	1.087	1.022
Jining	0.990	0.981	0.942	1.050	0.971
Taian	1.047	0.985	1.041	1.006	1.032
Weihai	0.951	1.021	0.969	0.981	0.971
Rizhao	0.912	0.987	1.000	0.912	0.900
Laiwu	0.969	0.951	1.000	0.969	0.921
Linyi	0.970	1.035	0.981	0.989	1.004
Dezhou	1.009	0.982	1.011	0.998	0.991
Liaocheng	1.037	1.026	1.095	0.947	1.064
Binzhou	0.956	0.997	0.969	0.987	0.954
Heze	1.048	0.973	1.021	1.026	1.020
Average	0.991	1.008	1.003	0.988	0.998

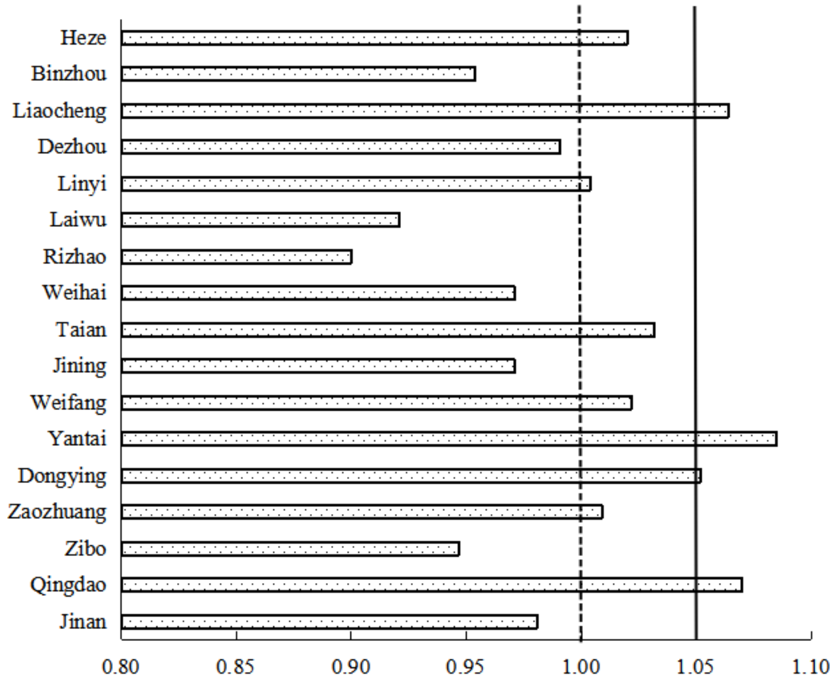

Figure 2: Distribution of M-index of technological R&D efficiency in cities of Shandong Province

(1) Level 1: M ∈ [1.05, +∞]

It includes Qingdao, Yantai, Liaocheng and Dongying. The technical output efficiency of these cities increased by more than 5 per cent per annum. Qingdao's M-index is 1.070, which represents an average annual increase of 7 per cent in the efficiency of technological output. The changes in the decomposition indices are all above 1, indicating that technological output has been maximized with

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limited inputs of technological resources, and therefore its returns to scale have remained constant. Yantai, Liaocheng and Dongying are similar in that the improvement in technical output efficiency is the result of a combination of TECH and EFF. However, from the decomposition of EFF, the SE change index of all three cities is less than 1, which is in an ineffective state, limiting the further improvement of technical output efficiency.

(2) Level 2: M=[1, l.05)

It includes five cities: Tai'an, Weifang, Heze, Zaozhuang and Linyi. The efficiency of technical output in these cities has been slow to improve, with an average annual growth rate of less than 5 per cent. A decomposition of the M-index reveals that in Zaozhuang and Weifang, the EFF and the TECH are greater than 1. From the decomposition of EFF, Zaozhuang lacks SE, while Weifang is weak in PEFF. Tai'an and Heze are similar in that only the TECH is less than 1, suggesting that the level of technology restricts the further improvement of EFF in two cities. In Linyi, on the contrary, only the TECH is greater than 1, and the rest of the indices are less than 1. This indicates that its resource allocation efficiency needs to be improved, and the scale of operation needs to be improved.

(3)Level 3: M=[0，l)

It includes eight cities: Jinan, Binzhou, Dezhou, Laiwu, Rizhao, Weihai, Jining, Zibo. The M-index for these cities is less than 1, indicating that there was no significant improvement in technical output efficiency during the study period. There was no change in EFF and a slight decrease in technical level in Jinan. There is a large potential for improvement in both PEFF and SE in Zibo and Weihai. TECH and PEFF in Jining are the main limiting factors. The three cities of Rizhao, Dezhou and Laiwu, in addition to the level of technology, SE is also a major factor limiting efficiency improvements. All indices for Binzhou City are less than 1.

4.2. Analysis of the efficiency of technology transfer in stage II

At the overall level, from the data in Table 3, it can be seen that the M-index of technological transformation efficiency is less than 1 from 2015 to 2018 in Shandong Province, with the average is 0.904. Therefore, in general, the technological transformation efficiency in Shandong Province has a greater potential for future improvement. During this period, the average of EFF was 1.019 and has been increasing year by year, due to the increase in PEFF and SE. The average of TECH is 0.887, indicating a downward in the level of technology. It shows that slow TECH is the main limiting factor for the efficiency of technological transformation in Shandong Province.

Table 3: M-index of technology transformation efficiency in Shandong Province from 2015 to 2018

Year	EFF	TECH	PEFF	SE	M-index
2015—2016	0.952	1.042	0.969	0.983	0.992
2016—2017	1.037	0.827	0.996	1.042	0.858
2017—2018	1.070	0.81	1.066	1.004	0.867
Average	1.019	0.887	1.009	1.009	0.904

Table 4: M-index of technology transformation efficiency in cities of Shandong Province

City	EFF	TECH	PEFF	SE	M-index
Jinan	1.054	0.885	0.876	1.204	0.933
Qingdao	0.918	0.849	1	0.918	0.78
Zibo	1.054	0.878	1.058	0.996	0.925
Zaozhuang	1.003	0.917	1	1.003	0.919
Dongying	1	0.874	1	1	0.874
Yantai	1.021	0.849	1	1.021	0.867
Weifang	1.054	0.858	1.122	0.939	0.904
Jining	1.043	0.873	1.053	0.99	0.91
Taian	0.959	0.895	0.941	1.019	0.859
Weihai	0.979	0.917	0.96	1.02	0.898
Rizhao	1	0.887	1	1	0.887
Linyi	1.05	0.894	1.029	1.02	0.939
Dezhou	1.113	0.896	1.083	1.028	0.997
Liaocheng	0.921	0.887	0.932	0.988	0.817
Binzhou	1.112	0.971	1.128	0.985	1.08
Heze	1.044	0.874	1	1.044	0.912
Average	1.019	0.887	1.009	1.009	0.904

At the regional level, the trend of technology transfer efficiency in each city of Shandong Province is shown in Table 4. The only city with an M-index greater than 1 is Binzhou. Its M-index is 1.080, indicating a growing trend in technology transformation efficiency. It shows that although Binzhou has low technical output efficiency during the study period, it has high technical transformation efficiency. Cities with $0.9 \leq M < 1$ include Jinan, Zibo, Zaozhuang, Weifang, Jining, Linyi, Dezhou and Heze. The M index of these cities is close to 1, indicating a slight decreasing trend of technology transformation efficiency in these cities. The M-index of the other cities is less than 0.9, indicating a significant decreasing in the efficiency of technological transformation in these cities during the study period. The decomposition of the M-index further shows that the level of technology is the main factor influencing the transformation efficiency of the cities.

5. Conclusions and recommendations

In this paper, from the theory of innovation value chain, the DEA-Malmquist model was used to calculate the second-stage M index of urban innovation in Shandong Province, and the following conclusions were obtained through the analysis:

(1) At the overall level, in the technology R&D stage, the average of M-index is 0.998 in Shandong province, indicating that the productivity of technological innovation has remained basically unchanged, mainly affected by slow TECH and declining SE. In the technology transformation stage, the average of M index of technology transformation efficiency in Shandong Province is 0.904, which is relatively weak, and its main limiting factor is the slow TECH.

(2) At the regional level, in the technology R&D stage, there are significant differences in the M-index between cities and for different reasons. In the technology transformation stage, except for Binzhou, the technological transformation efficiency of the rest of the cities shows different degrees of decreasing, and TECH is the main limiting factor for each city.

Based on the results of the study, policy recommendations for improving the innovation efficiency of cities in Shandong Province are proposed:

(1) Increase the rate of TECH, with the help of modern information technology. Whether the overall level or the regional level, the innovation efficiency of Shandong Province and its cities is inhibited by TECH during the two stages of innovation. TECH is a central element in improving the efficiency of innovation. This also fully reflects the inherent requirements of high-quality development. Improvements in the efficiency of innovation, fuelled by the "soft power" of TECH, are the direction to be pursued in this new era and stage. The level of informatisation determines the absorptive capacity of knowledge spillovers and has an impact on regional TECH. Information platforms, data processes and other information technology means have become an important support for technological innovation and an effective tool to enhance the effectiveness of innovation. With the development of modern information technology, the digital information model is deeply integrated into all aspects of life. First, the Internet will be deeply integrated with education to create a new education ecology and service model. This will accelerate the cultivation of knowledge-based, complex and innovative talents, enhance the quality of human innovation factors and maximize the effectiveness of human capital. Secondly, relying on block-chain, cloud computing and other information technologies, we will grow a number of core leading industries and seize the high ground of the fourth industrial revolution.

(2) Configure different innovative programme for different cities. For cities with low SE, the scale of production should be reasonably optimized, focusing on industrial cluster development to give full play to the effect of economies of scale. For cities with insufficient PEFF, emphasis should be placed on strengthening the training of high-quality management personnel, establishing a sound management system, optimizing the innovation environment and improving the internal operation mechanism of the city.

(3) Promote the process of innovation integration through the establishment of regional innovation synergy mechanisms. In order to promote the integrated development of regional innovation in Shandong and comprehensively enhance the overall effectiveness of innovation, it is necessary to break down regional administrative barriers, strengthen inter-regional innovation collaboration, integrate and optimize the allocation of resources, improve the long-term synergistic mechanism of regional innovation. Firstly, it is necessary to establish a coordinating organization for the integration of innovation between cities, to jointly formulate and publish various plans across regions, and to establish a mechanism for common regional interests; Secondly, we should give full play to the role of

regional industry associations to coordinate and solve the problems of innovation and integration of industries and enterprises; Thirdly, an integrated innovation service system should be established, which is conducive to the open sharing of infrastructure and the promotion of regional innovation interaction. Fourthly, regional cooperation and development forums can be organized to fully discuss regional innovation topics, promote communication and cooperation among various types of innovation entities, and enhance the transmission and exchange of innovation resources.

Acknowledgements

This study was supported by Shandong province humanities and social sciences project (2020-NDJJ-23).

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