Evaluation of innovation efficiency of high-tech enterprise based on DEA and Malmquist index under the background of sustainable development

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Abstract

Purpose – This paper aims to promote the higher quality development of high-tech enterprises in China. While science and technology have greatly promoted human civilization, resources have been excessively consumed and the environment has been sharply polluted. Therefore, it is particularly important for current enterprises to make use of scientific and technological innovation to maximize the benefits of mankind, minimize the loss of nature, and promote the sustainable development of our country.

Design/methodology/approach – By using DEA-Banker-Charnes-Cooper (BCC) model and DEA-Malmquist model, this paper comprehensively examines the innovation efficiency of high-tech enterprises from both static and dynamic perspectives, and conducts a provincial comparative study with the panel data of ten representative provinces from 2011 to 2020.

Findings – The research findings are as follows: the rapid number increase of high-tech enterprises in most provinces (cities) is accompanied by an ineffective input–output efficiency; the quality of high-tech enterprises needs to comprehensively examine both input–output efficiency and total factor productivity; and there is not a positive correlation between element investment and innovation performance.

Research limitations/implications – Because the DEA model used in this paper assumes that the improvement direction of invalid units is to ensure that the input ratio of various production factors remains unchanged but sometimes the proportion of scientific and technological activities personnel and the total research and development investment is not constant. In the future, the nonradial DEA model can be considered for further research. Due to historical data statistics, more provinces, cities and longer panel data are difficult to obtain. The samples studied in this paper mainly refer to the provinces and cities that ranked first in the number of national high-tech enterprises in 2020. Limited by the number of samples, DEA analysis

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failed to select more input and output indicators. In the future, with the accumulation of statistical data, the existing efficiency analysis will be further optimized.

Originality/value – Aiming at the misunderstanding of emphasizing quantity and neglecting quality in the cultivation of high-tech enterprises, this paper comprehensively uses DEA-BCC model and DEA Malmquist index decomposition method to make a comprehensive comparative study on the development of high-tech enterprises in ten representative provinces (cities) from two aspects of static efficiency evaluation and dynamic efficiency evaluation.

Keywords Sustainable development, Innovation efficiency, DEA-BCC model, DEA-Malmquist model, High-tech enterprise

Paper type Research paper

1. Introduction

These years, the Chinese economy is experiencing exponential growth and China has become the second largest economy in the world, but the accompanying ecological environment problems are also becoming more and more serious. Ecological deterioration and other issues are important factors affecting economic and social development. The Chinese Government places great importance to sustainable development issues such as the ecological environment and has made a series of efforts. Under the conditions of economic slowdown and tighter resource constraints, environmental protection efforts have not been relaxed. China's sustainable development level has been rising in recent years. In addition, as a responsible big country, China has set the goals of "carbon peak" in 2030 and "carbon neutrality" in 2060, which raises the bar for China's sustainable development level. Facing the pressure of ecological environment and the complex international economic situation, China urgently needs to turn its attention to improving the efficiency of sustainable development and explore a high-quality path of sustainable development. Among them, Sci-Tech innovation, as an important foundation and key means of sustainable development (Wang and Fan, 2022), is the best choice to promote sustainable development when the constraints of natural resources and ecological environment are increasingly tight.

As a knowledge and technology intensive economic unit that continuously carries out research and development (R&D) and technology transformation, high-tech enterprise is an important carrier of Sci-Tech innovation, the core force of the development of national high-tech industries and the new force of regional innovation (Zhang and Lv, 2013). The outbreak of COVID-19 has not only exerted great influence on China's economy and people's lives, but also brought challenges and opportunities to high-tech enterprises. During the epidemic prevention and control period, all kinds of high-tech enterprises actively applied their Sci-Tech innovation achievements to the new scene of epidemic prevention and control, such as the intelligent analysis system for the detection and quantification of COVID-19, mobile disinfection and sterilization robots, mobile nucleic acid detection vehicles, wearable wireless thermometers and unmanned logistics robots, which not only provided important support for the epidemic prevention and control work but also further established the important position of high-tech enterprises in the development of China's economy and society.

With the in-depth promotion of the strategy of strengthening the country through science and technology, relevant ministries and commissions such as the Ministry of science and technology and provincial (municipal) local governments have issued many policies and measures to vigorously promote the cultivation and identification of high-tech enterprises. As the number of high-tech enterprises in China increases rapidly, a competition for cultivating and developing the high-tech enterprises have been quietly launched across the country. The number of high-tech enterprises has become a major assessment indicator for many local science and technology departments, and even one of the indicators to assess the efficiency of regional high-quality development. Some studies have found that the number of enterprises has an insignificant negative impact on innovation efficiency (Han, 2010), and the more enterprises in a region, the less conducive it is for them to improve technological innovation efficiency (Guo *et al.*, 2020). Which means that the efficiency of regional innovation is not closely linked to the number of enterprises. In particular, for the transformation of China's economy from high-speed growth to high-quality development, improving development efficiency and quality is a more important goal. Therefore, carrying out the evaluation of innovation efficiency of high-tech enterprises and establishing a correct development orientation of high-tech enterprises are significant to the rational allocation of scientific and technological resources, the optimization of economic and industrial structure, and the realization of high-quality development. This paper comprehensively inspects the innovation efficiency of high-tech enterprises by using the DEA-Banker-Charnes-Cooper (BCC) model and the DEA-Malmquist model, then proposes three suggestions to push the higher quality development of Chinese high-tech enterprises based on the findings.

2. Literature review

On the research about high-tech enterprises, a growing number of scholars begin to show interest in the sustainable development and innovation ability of high-tech enterprises. About the evaluation of innovation efficiency of high-tech enterprises, the existing literature mainly focuses on two aspects, multilevel efficiency analysis and influencing factor evaluation. Among them, the former mainly includes three levels: region, industry and enterprise; The latter mainly determines the influencing factors through the evaluation of the innovation efficiency of high-tech enterprises, then puts forward the path to optimize the innovation efficiency. In addition, this paper will also review and discuss the evaluation methods of enterprise innovation efficiency.

2.1 Sustainable development of high-tech enterprises

In terms of the sustainable development of high-tech enterprises, Pylaeva *et al.* (2022) proposed a new method to identify sustainable high-tech enterprises; Cochran and Rauch (2020) better solved the problems of sustainability and industry 4.0 from the view of enterprise sustainable development. Yang and Wang (2020) proposed to establish an ecosystem of marine high-tech enterprises from the view of sustainable development; Law and Gunasekaran (2012) studied the key factors that promote Hong Kong's high-tech enterprises to adopt and implement sustainable development strategies; Du *et al.* (2022) evaluated the effect of high-tech industries and renewable energy on consumption-based carbon emissions in Middle Eastern and Northern Africa countries. Liu *et al.* (2020) used the lasso regression method to find out the factors that affect the efficiency of green technology innovation in high-tech industries within each cluster area; Chen *et al.* (2021) based on the three-stage ultra-efficient data envelopment analysis (DEA) model of cooperative game, studied its application in the R&D of green innovation in China's high-tech industry.

In accordance with innovation of high-tech enterprises, Ye *et al.* (2022) researched on the impact of R&D agglomeration and economic policy uncertainty on innovation of high-tech enterprises in China. (Li and Zhang, 2021) studied the independent innovation ability of high-tech enterprises based on field programmable gata array processors and dynamic reconfiguration technology. Based on the insight into internal and external governance, Lin *et al.* (2020) discussed how management power and network centrality affect the innovation performance of high-tech enterprises in the big data environment. Ghazinoory and Hashemi (2021) studied whether tax incentives and direct funds can improve the innovation input and output of high-tech enterprises; Wang *et al.* (2020) constructed an industrial evaluation framework for high-tech industrialization based on two-stage network DEA to evaluate the technological innovation efficiency of China's high-tech industry.

2.2 Multilevel efficiency evaluation

At the regional level, Simonen *et al.* (2015) discussed the economic performance of high-tech enterprises in Finland; Raab and Kotamraju (2006) used DEA to assess the innovation efficiency of high-tech enterprises in 50 states of the USA; Li *et al.* (2020) used the DEA method to evaluate the innovation efficiency of high-tech enterprises in the Beijing Tianjin Hebei region and found that the three places in Beijing Tianjin Hebei have shortcomings such as unreasonable resource allocation and an imperfect coordination mechanism and put forward suggestions such as strengthening the linkage and integration of the three places, providing independent innovation ability and increasing government investment.

At the industrial level, for example, Chen and Yeh (2005) used DEA to analyze the development efficiency of six high-tech industries; Guo *et al.* (2018) studied from the perspective of industrial development, used DEA method to evaluate the input–output efficiency of high-tech enterprises in different technology fields and concluded that there are certain differences in the input–output efficiency between high-tech enterprises in different technology fields; LV *et al.* (2017) used DEA to evaluate the innovation efficiency with high-tech enterprises and individual enterprises in different technology fields as decision-making units, and concluded that the innovation efficiency of technology enterprises in the four technology fields of electronic information, new materials, new energy and resources in the environment is high.

From the perspective of enterprise, Chen *et al.* (2014) used the random effect model to test the data of China's listed companies from 2004 to 2006 and drew a conclusion that the innovation efficiency of non-state-owned holding enterprises was remarkably better than that of state-owned holding enterprises; Based on the two-stage value chain theory, Xiao *et al.* (2015) concluded that the innovation efficiency of Chinese domestic funded enterprises, Hong Kong, Macao, Taiwan-funded enterprises and foreign-funded enterprises increased successively, and the efficiency difference was obvious.

Through the above literature review, which can be found that the research on the evaluation of innovation efficiency of high-tech enterprises has attracted the attention of a host of scholars, and the existing research has also been comprehensively analyzed from macro to micro, which has laid the foundation for this paper. However, with the development of the identification of high-tech enterprises, the quantity of high-tech enterprises in various regions has expanded rapidly. The relationship between the quantity of high-tech enterprises and the innovation efficiency of high-tech enterprises is also a matter of concern. Therefore, this paper evaluates the innovation efficiency of China's high-tech enterprises from the perspective of the number of high-tech enterprises in each region.

2.3 Evaluation of influencing factors

In terms of independent innovation ability, Hu and Zhou, (2018) used the DEA and Malmquist index methods to calculate the innovation efficiency of high-tech industries in the Yangtze River economic belt. Studies have found enterprise-independent innovation and government support are the main influencing power in improving the innovation efficiency of high-tech industries. Based on the panel data of high-tech industries in the Beijing Tianjin Hebei region from 2010 to 2017, Li *et al.* (2020) used DEA to evaluate the innovation efficiency of high-tech enterprises in Beijing Tianjin Hebei region, and believed that improving the independent innovation ability of enterprises would raise the innovation efficiency of enterprises.

In terms of government support, such as Dou *et al.* (2020) used the three-stage DEA model to evaluate the innovation efficiency of the sample enterprises, and through the counterfactual estimation and intermediary effect model, it was explored the identification policy of high-tech enterprises can raise the innovation efficiency in the technology research and development stage. Bronzini and Piselli, (2016) believed that the government R&D subsidy policy had a positive impact on the quantity of patent applications of the company.

In terms of the quality of workers, Burton *et al.* (2009) believe that employees with high job embeddedness can take the initiative to work and improve job performance; Mumford (2000) believes that the knowledge discovery and working atmosphere of R&D personnel will also affect innovation performance. Li *et al.* (2015) studied the relationship between R&D personnel's self-efficacy, job embeddedness and innovation efficiency by using structural equation model and proposed that the innovation efficiency of high-tech enterprises can be improved by improving R&D personnel's self-efficacy and job embeddedness.

From the above analysis, we can see that the innovation efficiency of enterprises is relevant to government support, independent innovation ability of enterprises and various factors of enterprise employees. By analyzing the influencing factors of enterprise innovation efficiency, we can provide reference for the improvement of enterprise innovation efficiency, which has guiding significance for reality. Through the evaluation of the innovation efficiency of enterprises in the top ten provinces (cities) with the number of high-tech enterprises, this paper explores the relationship between the number of enterprises and the innovation efficiency of enterprises, and provides reference for the relevant policies to improve the innovation efficiency of high-tech enterprises.

2.4 Relevant evaluation methods

Among the existing evaluation methods of enterprise innovation efficiency, factor analysis, grey evaluation, stochastic frontier analysis and DEA are commonly used.

Because DEA does not need dimensionless processing of indicators, it can directly analyze technical efficiency and scale efficiency without defining a special function form, so it has a wider range of applications. For example, Fang *et al.* (2020) applied the Charnes-Cooper-Rhodes and BCC models in DEA to analyze the technological innovation efficiency of 23 Chinese new energy vehicle listed enterprises from 2013 to 2018; Lee and Parka, (2009) used DEA to evaluate the technological innovation efficiency of equipment manufacturing industry in many Asian countries; Kortelainen (2008) applied DEA to evaluate the innovation efficiency of 20 EU Member States.

Furthermore, Fare *et al.* (1994) combined the Malmquist index used to study the indifference curve with DEA so as to measure the change of efficiency in different periods and proposed the DEA Malmquist model to analyze the dynamic change of total factor productivity, which has been widely used by many scholars. For example, Sha and Wang (2022) used DEA and Malmquist index models to calculate the innovation efficiency of nine provinces and regions in the Yellow River Basin.

It can be seen that the traditional DEA model takes no account of the impact of environmental factors and random errors on the efficiency evaluation of the decision-making unit (DMU) and can eliminate management inefficiency, environmental factors and random errors, which can obviously reflect the efficiency of DMU itself. The DEA Malmquist model, which combines the Malmquist index with DEA, can overcome the disadvantage that the traditional DEA model can only do static efficiency analysis so as to better solve the dynamic efficiency and total factor efficiency. Therefore, the research based on the DEA model or model variant is quite mature, and it is very consistent with the research theme of this paper. This paper will use the traditional DEA model and the DEA Malmquist model to measure the innovation efficiency of high-tech enterprises, respectively.

3. Static efficiency evaluation based on DEA-BCC model

Referring to the literature related to the input–output efficiency of high-tech industries (Guo *et al.*, 2018; Si and Li, 2017), and considering the continuity and availability of data, this paper selects the internal expenditure of scientific and technological activities personnel and R&D funds as input indicators, and the total income and export foreign exchange earnings as output indicators. At the same time, considering the impact of scale efficiency on the measurement results, this section adopts the scale income and input-oriented DEA-BCC model to make a horizontal comparison of input–output efficiency of different provinces (cities) through the average data from 2011 to 2020 and the time point data in 2020 (Guo *et al.*, 2018).

3.1 Horizontal comparison of average input–output efficiency from 2011 to 2020

As shown in Table 1, from the angle of comprehensive technical efficiency, only the average input–output efficiency of Shandong from 2011 to 2020 is effective, and the invalidity of the comprehensive efficiency of other provinces (cities) is due to the invalidity of technical efficiency and scale efficiency. Among them, Jiangsu ranks second among the ten provinces (cities) in terms of pure technical efficiency and scale efficiency. The ranking of pure technical efficiency in Zhejiang, Shanghai, Beijing, Hubei and Anhui lags behind their scale efficiency, and the ineffectiveness of their comprehensive technical efficiency is due to the ineffectiveness of pure technical efficiency to a greater extent. The pure technical efficiency of Guangdong, Tianjin and Sichuan is ahead of their scale efficiency, and the inefficiency of their comprehensive technical efficiency is caused by the inefficiency of scale efficiency to a greater extent.

Table 1. Calculation results of average input–output relative efficiency of ten representative provinces (cities) from 2011 to 2020

Province (city)	Crste	Ranking	Vrste	Ranking	Scale	Ranking
Beijing	0.8338	10	0.9132	8	0.9131	7
Guangdong	0.8907	6	0.9812	5	0.909	8
Jiangsu	0.9995	2	0.9997	2	0.9998	2
Zhejiang	0.8902	7	0.8995	10	0.9896	3
Shanghai	0.8815	8	0.9052	9	0.9742	5
Shandong	1	1	1	1	1	1
Hubei	0.955	3	0.9763	6	0.9773	4
Anhui	0.8995	4	0.9726	7	0.9243	6
Sichuan	0.876	9	0.9967	3	0.8789	10
Tianjin	0.892	5	0.989	4	0.9028	9

Notes: "Crste" represents the comprehensive technical efficiency level, "Vrste" represents the pure technical efficiency level, "Scale" represents the scale efficiency level. The same below
Source: Table by authors

3.2 Horizontal comparison of input–output efficiency in 2020

As shown in Table 2, from the perspective of comprehensive technical efficiency, the average efficiency of ten representative provinces (cities) is 0.9561, less than 1, which means that there are provinces (cities) with insufficient input–output efficiency. Specifically, the comprehensive technical efficiency of Guangdong, Zhejiang, Shanghai and Shandong is effective, which shows that the input–output of these four provinces (cities) is relatively balanced in 2020, and the output is maximized under certain input.

From the perspective of pure technical efficiency, the pure technical efficiency of Beijing, Guangdong, Zhejiang, Shanghai, Shandong, Hubei, Sichuan and Tianjin is effective, indicating that under the existing industrial scale, the technical level of these eight provinces (cities) in 2020 is advanced, their input and output levels are high, and there is no input redundancy or insufficient output. Whereas, the pure technical efficiency of Jiangsu and Anhui is less than 1, indicating that under the existing industrial scale, the technical level of the two places needs to be improved, and there is currently input redundancy or insufficient output.

Based on the analysis of the average input–output efficiency of ten provinces (cities) from 2011 to 2020 and the input–output efficiency of 2020, the findings are below:

- Shandong: The average input–output efficiency from 2011 to 2020 and the time point input–output efficiency in 2020 are both effective, which shows that the comprehensive technological development level of Shandong Province determines the shape of the production frontier of China's high-tech enterprises at present. From now on, we should take the lead in improving technical standards and promoting Pareto improvement of the production frontier, so as to push for the development of the whole industry.
- Guangdong, Zhejiang and Shanghai: The average input–output efficiency from 2011 to 2020 is less than 1, but the input–output efficiency at the time points of 2020 is effective, indicating that the input scale of the three provinces (cities) is becoming more reasonable. In the future, it is suggested to continue to develop according to the current production and operation modes.
- Hubei, Sichuan and Tianjin: The average input–output efficiency from 2011 to 2020 and the time point input–output efficiency in 2020 are less than 1, due to the

Province (city)	Crste	Vrste	Scale	Scale effectiveness
Beijing	0.826	1	0.826	drs
Guangdong	1	1	1	–
Jiangsu	0.995	0.997	0.998	irs
Zhejiang	1	1	1	–
Shanghai	1	1	1	–
Shandong	1	1	1	–
Hubei	0.996	1	0.996	irs
Anhui	0.876	0.989	0.886	irs
Sichuan	0.902	1	0.902	irs
Tianjin	0.966	1	0.966	irs
Average	0.9561	0.9986	0.9574	

Note: "drs" stands for diminishing returns to scale, "irs" stands for increasing returns to scale and "–" stands for constant returns to scale
Source: Table by authors

Table 2. Calculation results of input–output relative efficiency of high-tech industries in ten representative provinces (cities) in 2020

inefficiency of scale efficiency during the phase of increasing returns to scale. In the future, it is suggested to expand the input scale of production factors.

- Beijing: The average input–output efficiency from 2011 to 2020 and the time point input–output efficiency in 2020 are less than 1, due to the inefficiency of scale efficiency during the phase of diminishing returns to scale. In the future, it is suggested to appropriately reduce the input of production factors, optimize the structure of production input and strengthen internal supervision.
- Jiangsu and Anhui: The average input–output efficiency from 2011 to 2020 and the time point input–output efficiency in 2020 are less than 1, which is caused by the ineffectiveness of technical efficiency and scale efficiency during the phase of increasing returns to scale. In the future, it is suggested to expand the input of production factors and improve the management level.

4. Dynamic efficiency evaluation based on data envelopment analysis – Malmquist model

This section considers to reflect the changes in the relative efficiency of input and output of high-tech enterprises in different provinces (cities), and adopts the DEA Malmquist model to conduct a vertical comparison of input–output efficiency through the decomposition of the average Malmquist index and the changes in total factor productivity from 2011 to 2020 (Yu *et al.*, 2018).

4.1 Average Malmquist index and its decomposition of ten representative provinces (cities) from 2011 to 2020

Table 3 shows that, on average, the total factor productivity of high-tech enterprises in ten representative provinces (cities) increased by 6.28% from 2011 to 2020. Among them, the pure technical efficiency increased by 0.6%, the scale efficiency increased by 0.03% and the technological progress index increased by 5.59%.

In terms of provinces (cities), the total factor productivity of high-tech enterprises in the ten representative provinces (cities) from 2011 to 2020 was greater than 1. Among them, the

Province (city)	Effch	Techch	Pech	Sech	Tfpch
Beijing	1.012	1.004	1.011	1.001	1.017
Guangdong	1.01	1.075	1.009	1.001	1.086
Jiangsu	1	1.054	1	1	1.054
Zhejiang	1.037	1.078	1.033	1.004	1.118
Shanghai	1	1.063	1	1	1.063
Shandong	1	1.086	1	1	1.086
Hubei	0.999	1.027	1	0.999	1.026
Anhui	0.987	1.057	0.998	0.989	1.043
Sichuan	1.013	1.038	1	1.013	1.052
Tianjin	1.005	1.077	1.009	0.996	1.083
Average	1.0063	1.0559	1.006	1.0003	1.0628

Notes: “Effch” refers to the change of comprehensive technical efficiency, “Techch” refers to the change of technology, “Pech” refers to the change of pure technical efficiency, “Sech” refers to the change of scale efficiency and “Tfpch” refers to total factor productivity. Where, Tfpch = Effch × Techch, Effch = Pech × Sech

Source: Table by authors

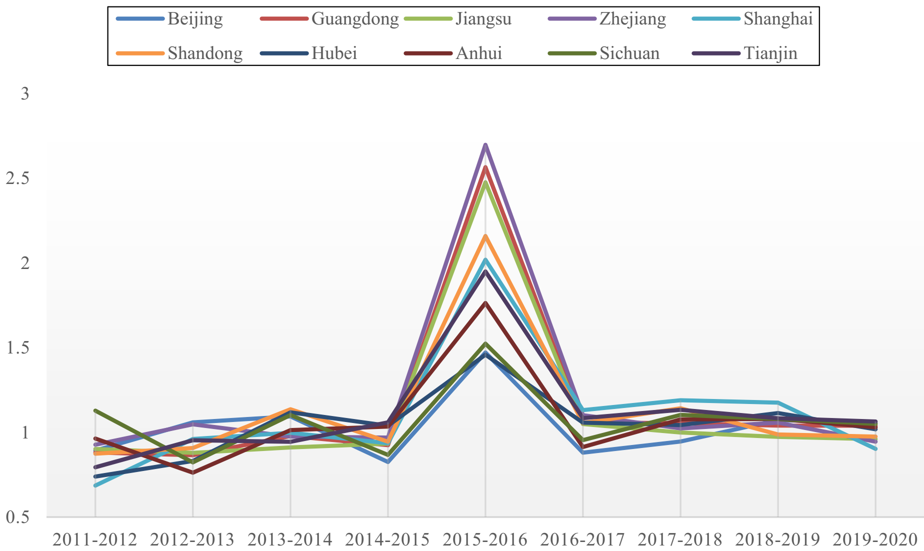
Table 3. Average Malmquist index and its decomposition of ten representative provinces (cities) from 2011 to 2020

comprehensive technical efficiency of Jiangsu, Shanghai and Shandong provinces (cities) remains unchanged, all thanks to the rise of the technological progress index. The advancement of total factor productivity in other provinces (cities) comes from the mixed effect of comprehensive technical efficiency and the technological progress index. Specifically, Hubei and Anhui are affected by the decline of scale efficiency, which causes the decline of comprehensive technical efficiency. The advancement of total factor production efficiency is mainly because of the greater advancement of the technological progress index. The comprehensive technical efficiency and technological progress index of Beijing, Guangdong, Zhejiang, Sichuan and Tianjin have increased to varying degrees, which together contributed to the advancement of total factor productivity, but the scale efficiency of Tianjin has decreased and the scale efficiency of Sichuan has increased.

4.2 Annual total factor productivity changes in ten representative provinces (cities) from 2011 to 2020

From 2011 to 2020, the annual total factor productivity of high-tech enterprises in ten representative provinces (cities) showed a fluctuating trend of rising first and then declining, reaching a peak between 2015 and 2016. According to the overall changes of the start and end years, it can be divided into three types, as shown in Figure 1:

1. (1) Total factor productivity rise: Beijing, Guangdong, Hubei, Anhui and Tianjin belong to this type. The initial annual total factor productivity is less than 1. After slow changes and fluctuations, the total factor productivity from 2019 to 2020 has achieved a breakthrough of more than 1, showing a good development trend.
2. (2) Total factor productivity increased, but the growth rate became smaller. Sichuan belongs to this type, and the total factor productivity in the initial year and 2019–



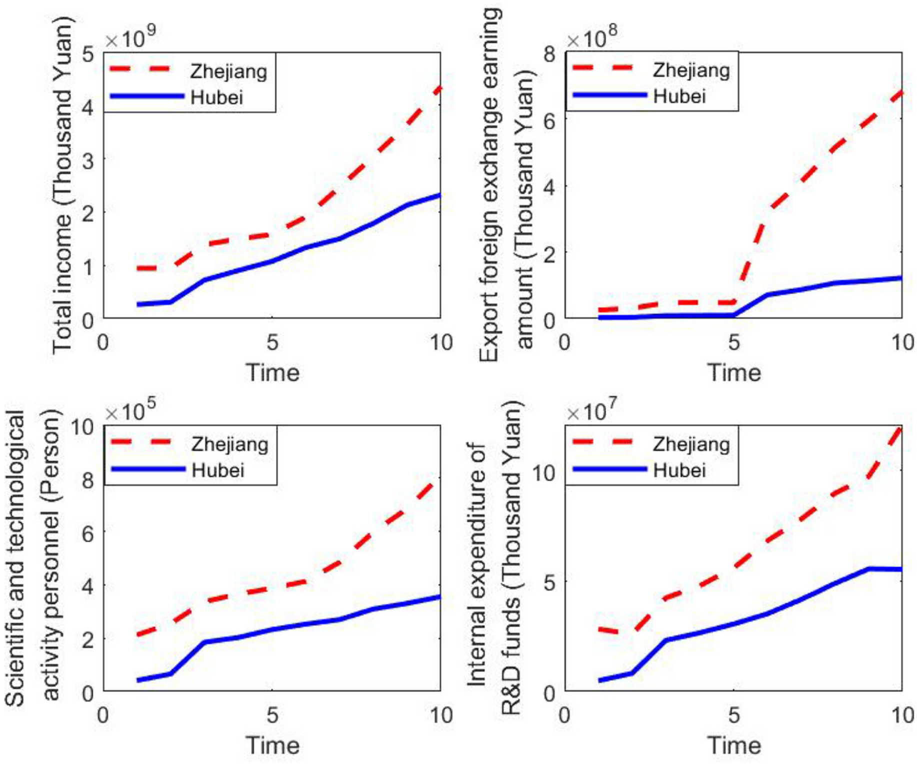
Source: Figure by authors

Figure 1. Changes in total factor productivity in ten representative provinces (cities) from 2011 to 2020

2020 was greater than 1, but the total factor productivity in 2019–2020 was significantly less than that in the initial year, showing a trend of slowing down.

(3) Total factor productivity decreased, but the decline became smaller. Jiangsu, Zhejiang, Shanghai and Shandong belong to this type. The total factor productivity in the initial year and 2019–2020 is less than 1, but the total factor productivity in 2019–2020 is remarkably better than that in the initial year, showing a positive trend of increasing growth.

In addition, the total factor productivity of five provinces and cities, including Guangdong, Zhejiang, Shanghai, Jiangsu and Shandong, exceeded 2 from 2015 to 2016, which was mainly affected by the output index of "export foreign exchange earning." For example, we chose the province with the lowest total factor productivity in 2016 (Hubei: 1.456) and the province with the highest total factor productivity (Zhejiang: 2.694) for comparison, as shown in Figure 2. The four subcharts in Figure 2 show the change trends of the four indicators of total income, export foreign exchange earnings, scientific and technological activity personnel and internal expenditure of R&D funds in Zhejiang and Hubei, respectively. It can be concluded that the total factor productivity of these two provinces is greatly affected by the output index of "export foreign exchange earnings." Hubei Province's



Source: Figure by authors

Figure 2.
Change trend of four indicators in Zhejiang and Hubei from 2011 to 2020

export foreign exchange earnings showed steady linear growth from 2015 to 2016, and its growth trend is almost the same as that of other years; Zhejiang Province showed linear growth before 2015 and exponential growth from 2015 to 2019. This growth trend was particularly obvious from 2015 to 2016.

5. Conclusions and suggestions

Aiming at the misunderstanding of emphasizing quantity and neglecting quality in the cultivation of high-tech enterprises, this paper comprehensively uses the DEA-BCC model and the DEA Malmquist index decomposition method to conduct a comprehensive comparative study of the development of high-tech enterprises in ten representative provinces (cities) from two aspects of static efficiency evaluation and dynamic efficiency evaluation.

5.1 Research conclusion

To estimate the cultivation and development level of high-tech enterprises, we cannot rely solely on the quantitative indicators of high-tech enterprises. Only in terms of input–output efficiency and total factor productivity can we more objectively evaluate the development quality of high-tech enterprises in different regions:

- The rapid increase in the quantity of high-tech enterprises in most provinces (cities) is accompanied by invalid input-output efficiency. In terms of average input–output efficiency from 2011 to 2020, except that Shandong is DEA effective, the other nine provinces (cities) have invalid scale efficiency, technical efficiency or both. In terms of input–output efficiency at the time point of 2020, except that Shandong, Guangdong, Zhejiang and Shanghai are DEA effective, the other six provinces (cities) need to make efforts in changing the scale of factor input and improving the management level.
- The quality of high-tech enterprises needs to comprehensively examine input–output efficiency and total factor productivity. Not the more input factors that affect innovation performance, the better. Shanghai has the problem of redundant input or insufficient output, and its total factor productivity is lower than that of most other provinces (cities), which is worthy of vigilance. At present, the input–output efficiency of Hubei, Anhui, Sichuan and Tianjin is relatively insufficient, but the total factor productivity is relatively high, and the prospect is promising.

5.2 Enlightenment suggestions

In an effort to further improve the innovation efficiency of high-tech enterprises in all provinces (cities) and promote the development of high-tech industries, the following suggestions are put forward:

- The national level should strengthen guidance to ensure that the policies of high-tech enterprises are in line with the goals of developing high-tech industries. Developing high-tech industries is a key measure to promote economy growth and structure of industry upgrade. Cultivating high-tech enterprises gets a head start for improving the innovation level of enterprises and promoting the development of high-tech industries. In essence, the policy of high-tech enterprises is a policy measure based on the enterprise level and oriented to industrial development. It is suggested that the state strengthen the evaluation of the development quality of high-tech enterprises and the driving role of high-tech enterprises in their industries/fields according to the "high tech fields supported by the state," and include it in the assessment standards for the identification of high-tech enterprises organized by all provinces (cities).

- Different provinces (cities) take differentiated measures to effectively promote the development of high-tech enterprises in light of local conditions. The input–output efficiency of Shandong, Guangdong, Zhejiang and Shanghai is relatively reasonable, and the total factor productivity is increasing. It is suggested to continue to develop according to the current production and operation modes in the future. The input–output efficiency of Hubei, Sichuan, Tianjin, Jiangsu and Anhui is relatively insufficient, and it is in the stage of increasing returns to scale, and the average value of total factor productivity is greater than 1. In the future, it is suggested to expand the input of production factors and vigorously develop them according to the current mode of production and operation. The input–output efficiency of Beijing is relatively insufficient during the phase of diminishing returns to scale, and the average total factor productivity is greater than 1. From now on, it is suggested to appropriately reduce the input of production factors and continue to develop in accordance with the current mode of production and operation.
- Build an exchange and cooperation platform to accelerate the linkage and interoperability development of high-tech enterprises in different provinces (cities). As the main force of innovation, high-tech enterprises should take the lead in growing into industry benchmarks and field leaders. It is suggested to bring into full play the role of industry associations/industrial alliances, build exchange and cooperation platforms for high-tech enterprises in different industries, break administrative boundaries and even market barriers between different provinces (cities), support knowledge sharing, resource exchange and business docking among high-quality high-tech enterprises, promote common progress and collaborative development of high-quality high-tech enterprises and expand the circle of friends of high-tech enterprises. Furthermore, by strengthening the communication and cooperation platform of high-tech enterprises and the publicity of high-quality high-tech enterprises, we will attract more scientific and technological enterprises to actively find benchmarks, gaps and developments so as to cultivate more high-tech enterprises with higher quality.

5.3 Research limitations

- Because the DEA model used in this paper assumes that the improvement direction of invalid units is to ensure that the input ratio of various production factors remains unchanged, sometimes the proportion of scientific and technological activity personnel and the total R&D investment is not constant. In the future, the nonradial DEA model can be considered for further research.
- Due to historical data statistics, more provinces (cities) and longer panel data are difficult to obtain. The samples studied in this paper mainly refer to the provinces (cities) that ranked first in the number of national high-tech enterprises in 2020. Limited by sample size, DEA analysis failed to select more input and output indicators. In the future, with the accumulation of statistical data, the existing efficiency analysis will be further optimized.

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