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Comparative Study on the Efficiency of Technological Innovation in Industrial Enterprises in the Yangtze River Economic Belt of China

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[Abstract]

The Yangtze River Economic Belt has abundant innovation resources and is a leader in innovation in China. In order to explore the efficiency of technological innovation of its industrial enterprises, this paper measures and analyzes the efficiency of technological innovation of industrial enterprises in the Yangtze River Economic Belt using DEA-Malmquist index method based on the panel data of industrial enterprises in 11 provinces and cities in the Yangtze River Economic Belt from 2011 to 2020. The results show that (1) according to the static DEA analysis, the overall level of technical efficiency of technological innovation of industrial enterprises in the Yangtze River Economic Belt is relatively low during 2011-2020; there are significant differences among the three regions in the upper, middle and lower reaches of the Yangtze River. (2) The dynamic Malmquist index shows that the overall Malmquist index of technological innovation of industrial enterprises in the Yangtze River economic zone during 2011-2020 shows an improving trend, and the main source of its improvement is technological change rather than the efficiency of the utilization of technological innovation factors.

▸ **Key words**: China, Technological Innovation, Efficiency, Malmquist index

[요 약]

본 연구는 중국에서 혁신자원이 가장 풍부하고 혁신을 선도하는 양쯔강경제벨트를 대상으로 공업의 기술혁신 효율성을 분석하고 있다. 분석기간은 2011년부터 2020년까지로 설정하고 있으며 분석에는 양쯔강경제벨트를 구성하는 11개 성 및 직할시를 이용하고 있다. 기술혁신의 효율성에는 정태적인 DEA 방법과 동태적인 Malmquist 지수를 이용한다. 투입변수는 R&D 투입인원과 R&D 경비지출을 이용한다. 산출변수는 R&D 프로젝트 수, 발명특허인정 수, 기술계약금액을 이용한다. 정태적인 DEA 분석결과에 의하면 2011-2020년 동안 양쯔강경제벨트의 전반적인 기술 효율성 수준은 상대적으로 낮게 나타나고 있다. 그러나 동태적인 Malmquist 지수는 2011년부터 2020년까지 전반적으로 상승 추세를 보이고 있다. 지역별로 보면 상류 지역의 효율성 변화가 가장 낮고, 중류 지역이 가장 높으며, 하류 지역이 가장 낮게 나타나고 있다.

▸ **주제어**: 중국, 기술혁신, 효율성, Malmquist 지수

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I. Introduction

With the formulation of China's national innovation goals and the deep implementation of the innovation-driven development strategy, innovation-driven development has become a major issue for China's economic growth. The Yangtze River Economic Belt is the region with the richest innovation resources in China[1].

It covers 11 provinces and cities, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan, and Guizhou. The area spans approximately 2.05 million square kilometers, accounting for 21.4% of China's land area, and its population and GDP both exceed 40% of the national total. The Yangtze River Economic Belt concentrates one-third of China's institutions of higher education and research institutions, as well as about half of China's academicians and scientific personnel. Its expenditure on research and development, the number of valid invention patents, and the proportion of sales revenue from new products account for 43.9%, 44.3%, and 50% of the national total, respectively[2].

It can be seen that the technological innovation of industrial enterprises in the Yangtze River Economic Belt is crucial for the implementation of China's innovation-driven development strategy. It also serves as the best window to observe the effectiveness of technological innovation in China's industrial enterprises. The technological innovation achievements of these industrial enterprises are not only significant for their own development but also inject new impetus into the overall economic growth of China.

However, the academic community's attention to the Yangtze River Economic Belt's technological innovation has not yet reached the required level. Therefore, based on considering the overall macroeconomic environment of China, this study selects relevant data on technological innovation in industrial enterprises in the Yangtze River Economic Belt from 2011 to 2020. The aim is to objectively reflect the actual situation of technological innovation during this period and provide decision-making basis for improving the efficiency of technological innovation in industrial enterprises in the Yangtze River Economic Belt.

II. Literature Reviews

Technological innovation is one of the important driving forces behind regional economic development. Through technological innovation, productivity and competitiveness can be enhanced, leading to economic growth. It can also optimize production processes, reduce costs, improve efficiency, and enhance the long-term market competitiveness and profitability of enterprises[3][4].

The efficiency of technological innovation is an important criterion for measuring the innovation capacity of industrial enterprises in a region and is a topic of significant academic interest. Studies conducted by Jiang(2012)[5], Xie, et al.(2013)[6], Chen, et al.(2017)[7], and Li (2017)[8] found that the efficiency of technological innovation in China's medium and large-sized enterprises showed a decline in the period of 2001-2008, and there were significant differences in the efficiency of technological innovation among different provinces and cities in China during the periods of 2003-2010, 2008-2014, and 2004-2014.

Hu, et al.(2018)[9] found that the efficiency of technological innovation in high-tech industries in the Yangtze River Economic Belt showed an upward trend during the period of 2011-2016, with an overall improvement in efficiency levels. Luo, et al.(2019)[10] and Bai, et al.(2021)[11] discovered regional differences in the efficiency of technological innovation in industrial enterprises in the Yangtze River Economic Belt during the periods of 2008-2017 and 2012-2017.

The above literature mainly adopts the DEA model or DEA-Malmquist index as research methods, which have been proven to be mature and reliable. The research focuses mainly on medium and large-sized enterprises, as well as industrial enterprises in the Yangtze River Economic Belt. Although there have been studies on the efficiency of technological innovation in industrial enterprises in the Yangtze River Economic Belt, the results have shown significant differences due to variations in the data used, and a consensus has not yet been reached.

Therefore, based on the existing research findings, this study cautiously selects relevant data on technological innovation in industrial enterprises in the Yangtze River Economic Belt from 2011 to 2020. It constructs an evaluation index system for the efficiency of technological innovation in industrial enterprises in the Yangtze River Economic Belt and applies the DEA-Malmquist index method to calculate and analyze it, aiming to enrich the research on the efficiency of technological innovation in industrial enterprises in the Yangtze River Economic Belt.

The potential academic contributions of this study are as follows: (1) This study, considering the background of China's macroeconomy, adopts relevant data from 2011 to 2020, which has not been used in previous studies; (2) When selecting output variables, this study takes into account the uncertainty of the cycle for patent application and approval and estimates the number of authorized invention patents for the current year, making the calculation results more realistic and reliable.

III. Research Methodology

1. DEA Model and Malmquist Index

Charnes, et al.(1978)[12] proposed the Data Envelopment Analysis (DEA) method based on the concept of technical efficiency introduced by Farrell(1957)[13].

Currently, the DEA model consists of two fundamental models, the constant returns to scale (CCR) model and the variable returns to scale (BCC) model. Considering that this study focuses on the technological innovation of industrial enterprises, which cannot remain in an optimal and constant steady state in the long term, the BCC model based on inputs is chosen to assess the efficiency of technological innovation in the Yangtze River Economic Belt.

Since the BCC model introduces Shephard(1970) concept of distance function, technical efficiency (TE) can be subdivided into pure technical efficiency(PE) and scale efficiency(SE) [14]. Efficiency is judged by the value of 1. When the efficiency index is less than 1, it means that the efficiency has not reached the DEA effective level; when the efficiency index is equal to 1, it means that the efficiency has reached the DEA effective level.

According to the research methodology and model proposed by Färe, et al.(1985)[15], Caves, et al.(1982)[16] proposed an expression for calculating the output-based Malmquist index. The Malmquist index can be decomposed into two components under the assumption of constant returns to scale, the efficiency change(EC) and the technological change(TC). If EC>1, it indicates that the management and resource allocation abilities of the industrial enterprises in the unit have improved, leading to efficiency improvement in their technological innovation. If EC<1, it represents efficiency deterioration. If TC>1, it signifies technological progress, and while TC<1 suggests technological regress.

Under the assumption of variable returns to scale, the efficiency change can be further decomposed into pure technical efficiency change(PEC) and scale efficiency change(SEC). If PEC>1, it indicates an improvement in efficiency when comparing the two periods. If SEC>1, it means that in period relative to period, the efficiency is closer to the constant returns to scale or the optimal scale in the long run. Conversely, if SEC<1, it implies that in period t+1 relative to period t, the efficiency is further away from the constant returns to scale or the optimal scale in the long run.

2. Variable Selection

Based on the beneficial research findings of scholars in the selection of input-output variables for industrial enterprises' technological innovation [17][18], and the current situation of technological innovation in industrial enterprises in the Yangtze River Economic Belt, this study carefully considers both human resources and financial resources. It selects R&D personnel in full-time equivalent and R&D expenditure as input variables. R&D personnel in full-time equivalent can standardize the workload of various research personnel, thereby objectively reflecting the actual human resource input in industrial enterprises' technological innovation. And R&D expenditure includes various expenses such as salaries of R&D personnel, purchase of experimental equipment, procurement of experimental supplies, and R&D expenses for scientific and technological cooperation, which can objectively reflect the financial input in technological innovation.

And, from the perspectives of technological achievements and economic outcomes, this study selects the number of R&D projects, the number of granted invention patents, and the total amount of technology contract transactions as output variables. Instead of using the commonly adopted metric of patent applications, this study utilizes the number of granted invention patents and the number of R&D projects to represent technological novelty. This is because compared to utility model patents and design patents, invention patents have the highest value and can better reflect the creativity of industrial enterprises in technological innovation. Taking into account the uncertainty in the application and approval process of invention patents[19], the study estimates the patent approval rate for each provinces and municipalities by dividing the number of granted invention patents by the number of patent applications.

To eliminate the influence of heterogeneity among provinces and municipalities, the sum of annual patent approval rates for each provinces and municipalities is divided by the total number of years (10 years from 2011 to 2020) to obtain the average approval rate. Then, the annual number of patent applications for each provinces and municipalities is multiplied by the average approval rate to estimate the number of granted invention patents for that year, thus improving the accuracy of the measurement. R&D projects are the basic organizational form for conducting R&D activities. They are typically defined by project proposals or contracts, specifying project tasks, objectives, personnel, and funding. They better reflect the ability of industrial enterprises to allocate technological innovation resources.

In addition, the total amount of technology contract transactions is used in this study to represent the economic outcomes of technological innovation, rather than using the commonly adopted metric of new product sales revenue. This is because the concept of new products is broad, and using new product sales revenue to measure economic outcomes may overstate the achievements. The total amount of technology contract transactions better reflects the actual economic outcomes of industrial enterprises' innovation efforts and also indicates their application capabilities for innovative achievements.

3. Data Selection and Sources

As mentioned in the introduction of this paper, after the reform and opening-up, the Chinese economy relied primarily on tangible factors of production such as capital stock, land, and labor forces to drive rapid economic growth. However, starting from 2011, China's annual GDP growth rate showed a declining trend, staying below 10% each year.

The main reasons for this were the severe overcapacity in China's lower-end manufacturing sector and the disorderly expansion of the real estate industry, which became major obstacles to sustained economic development. In fact, as early as 2007, the Chinese government emphasized the need to adjust the development model, shift towards an innovation-driven mode, and strengthen the role of enterprises in independent innovation. Industrial enterprises must rely on technological innovation to move up the value chain. Therefore, considering the growth of China's GDP and economic policies, the analysis in this paper focuses on the input-output data of industrial enterprises in the Yangtze River Economic Belt between 2011 and 2020. It is important to note that industrial enterprises here refer to enterprises with annual main business revenue of 20 million RMB or above. The data used from the China Statistical Yearbook and the China Science and Technology Statistical Yearbook.

IV. Empirical Analysis

1. DEA Analysis

From the static viewpoint, the DEA analysis of the technological innovation efficiency of industrial enterprises in the Yangtze River Economic Belt during the period of 2011-2020 are shown in table 1(due to space limitations, only the results for the years 2011, 2015, and 2020 are presented). The static DEA analysis of technological innovation efficiency is conducted at three levels, includes overall, regional, and provinces and municipalities levels, using three indicators, technical efficiency(TE), pure technical efficiency(PE), and scale efficiency(SE). At the overall level, the average of the mean values for the technological innovation efficiency of industrial enterprises in the Yangtze River Economic Belt during the period of 2011-2020 is 0.911. The average of the mean values for pure technical efficiency is 0.960, and the average of the mean values for scale efficiency is 0.950. However, none of these values reach the level of DEA efficiency, indicating that the technological innovation efficiency of industrial enterprises in the Yangtze River Economic Belt is relatively low. Additionally, the technical efficiency is influenced by both pure technical efficiency and scale efficiency, but the influence of scale efficiency is slightly greater.

At the regional level, the average values of technical efficiency exhibit a "high-low-medium" spatial distribution. The up stream region has the highest average value (0.946), the middle stream region has the lowest (0.852), and the down stream region is in the middle (0.921). The average values of pure technical efficiency show a "medium-low-high" spatial distribution. The up stream region is in the middle (0.991), the middle stream region has the lowest value (0.877), and the down stream region has the highest (0.992). The average values of scale efficiency display a "low-high-medium" spatial distribution. The up stream region has the lowest value (0.929), the middle stream region has the highest (0.971), and the down stream region is in the middle (0.955).

This indicates that there are spatial differences in technical efficiency, pure technical efficiency, and scale efficiency among the up stream, middle stream, and down stream regions of the Yangtze River. The technical efficiency of each region is influenced by both pure technical efficiency and scale efficiency. However, the technical efficiency in the up stream and down stream regions is slightly more affected by scale efficiency, while in the middle stream region, it is slightly more influenced by pure technical efficiency.

At the provinces and municipalities level, the results show that Sichuan province has achieved DEA efficiency levels in technical efficiency for the entire period of 2011-2020, with scale efficiency remaining constant. Chongqing municipality had four years of DEA-efficient technical efficiency during the same period. The technical efficiency in Chongqing is influenced by both pure technical efficiency (0.962) and scale efficiency (0.972), but the impact of pure technical efficiency is slightly

Table 1. DEA analysis Results

Regions/ provinces and municipalities		2011			2015			2020		
		TE	PE	SE	TE	PE	SE	TE	PE	SE
Up stream regions	Chongqing	0.925	0.961	0.962	1.000	1.000	1.000	0.938	0.961	0.976
	Sichuan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Guizhou	0.843	1.000	0.843	0.805	1.000	0.805	0.870	1.000	0.870
	Yunnan	1.000	1.000	1.000	1.000	1.000	1.000	0.867	1.000	0.867
	Mean	0.942	0.990	0.913	0.951	1.000	0.921	0.919	0.990	0.943
Middle stream regions	Jiangxi	0.607	0.679	0.894	0.763	0.813	0.939	0.933	0.970	0.962
	Hubei	0.649	0.650	0.997	1.000	1.000	1.000	0.993	1.000	0.993
	Hunan	1.000	1.000	1.000	0.709	0.710	0.999	0.887	0.910	0.975
	Mean	0.752	0.776	0.964	0.824	0.841	0.979	0.938	0.960	0.977
Down stream regions	Shanghai	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Jiangsu	0.681	1.000	0.681	0.684	1.000	0.684	0.780	1.000	0.780
	Zhejiang	0.988	1.000	0.988	1.000	1.000	1.000	1.000	1.000	1.000
	Anhui	0.891	0.906	0.983	1.000	1.000	1.000	0.911	0.918	0.992
	Mean	0.890	0.977	0.951	0.921	1.000	0.951	0.923	0.980	0.928
Overall	Mean	0.871	0.927	0.941	0.906	0.957	0.948	0.925	0.978	0.947

greater. However, scale efficiency decreased in one year. Guizhou province did not achieve DEA-efficient technical efficiency throughout the period. Its technical efficiency is influenced by scale efficiency (0.885), which increased over time. Yunnan province had five years of DEA-efficient technical efficiency, with scale efficiency (0.962) influencing its technical efficiency and showing an increasing or constant trend.

Jiangxi province had one year of DEA-efficient technical efficiency, influenced by both pure technical efficiency (0.877) and scale efficiency (0.949), with pure technical efficiency having a slightly greater impact. However, scale efficiency decreased for two years. Hubei province had four years of DEA-efficient technical efficiency, influenced by both pure technical efficiency (0.928) and scale efficiency (0.978), with pure technical efficiency having a slightly greater impact. However, scale efficiency decreased for four years. Hunan province had one year of DEA-efficient technical efficiency, influenced by both pure technical efficiency (0.825) and scale efficiency (0.987), with pure technical efficiency having a slightly greater impact. However, scale efficiency decreased for four years.

Shanghai municipality achieved DEA-efficient technical efficiency throughout the period, with scale efficiency remaining constant. Jiangsu province did not achieve DEA-efficient technical efficiency throughout the period, and its technical efficiency is influenced by scale efficiency (0.736), which decreased over time. Zhejiang province had eight years of DEA-efficient technical efficiency, influenced by scale efficiency (0.990), with scale efficiency decreasing for two years. Anhui province had four years of DEA-efficient technical efficiency, influenced by both pure technical efficiency (0.969) and scale efficiency (0.988), with pure technical efficiency having a slightly greater impact. However, scale efficiency decreased for six years.

These results indicate significant spatial differences in technical efficiency among the industrial enterprises in the 11 provinces and municipalities within the Yangtze River Economic Belt. This suggests that these regions' industrial enterprises exhibit significant variations in the intensive utilization of various technological innovation factors.

2. Malmquist Index Analysis

The Malmquist Index and its decomposition indices for the technological innovation efficiency of industrial enterprises in the Yangtze River Economic Belt during the period 2011-2020 are shown in tables 2 and tables 3. Dynamic analysis of technological innovation efficiency is conducted using four indicators, Malmquist index, Efficiency

Table 2. Malmquist Index by Annuals

Year	EC	TC	PEC	SEC	Malmquist Index
2011-2012	0.992	1.108	0.994	0.998	1.099
2012-2013	1.065	0.969	1.052	1.012	1.031
2013-2014	1.007	1.043	1.003	1.004	1.050
2014-2015	0.982	0.995	0.989	0.993	0.977
2015-2016	0.990	1.057	1.005	0.985	1.046
2016-2017	1.027	1.047	0.988	1.040	1.076
2017-2018	1.038	1.043	1.046	0.993	1.083
2018-2019	1.005	1.119	1.005	1.001	1.125
2019-2020	0.971	1.073	0.985	0.985	1.042
Overall Mean	1.008	1.050	1.007	1.001	1.058

Change (EC), Technological Change (TC), Pure Efficiency Change (PEC), and Scale Efficiency Change (SEC).

According to the data in table 2, the Malmquist index of technological innovation efficiency for industrial enterprises in the Yangtze River Economic Belt showed improvement during the periods of 2011-2020, except of 2014-2015. Among them, the largest increase in Malmquist index was observed in the period of 2018-2019 (12.5%). The period of 2012-2013 had the smallest increase in Malmquist index (3.1%). However, there was a decrease of 2.3% in the Malmquist index during the period of 2014-2015. The overall mean data shows that there have been improvements in the changes of technological efficiency, technological change, pure technical efficiency change, and scale efficiency change. Among them, the largest increase is observed in technological change (5%). Therefore, it can be inferred that technological change is the main driver behind the improvement in the Malmquist index of technological innovation efficiency for industrial enterprises in the Yangtze River Economic Belt during the period of 2011-2020, rather than the efficiency of utilizing technological innovation factors.

Looking at the decomposition indicators, the changes in technological efficiency have shown decreases of 0.8% in 2011-2012, 1.8% in 2014-2015, 1% in 2015-2016, and 2.9% in 2019-2020. However, improvements were observed in other years. Technological change experienced decreases of 3.1% in 2012-2013 and 0.5% in 2014-2015, but improvements were seen in other years. Pure technical efficiency change decreased by 0.6% in 2011-2012, 1.1% in 2014-2015, 1.2% in 2016-2017, and 1.5% in 2019-2020, while improvements were observed in other years. Scale efficiency change decreased by 0.2% in 2011-2012, 0.7% in 2014-2015, 1.5% in 2015-2016, 0.7% in 2017-2019, and 1.5% in 2019-2020, with improvements in other years. This indicates that the number of years with decreases in technological change is the lowest, and all years after 2015 showed improvements. It suggests that industrial enterprises in the Yangtze River Economic Belt increased their investment in technological innovation factors after 2015.

According to the data in table 3, the Malmquist index of technological innovation efficiency for industrial enterprises in the Yangtze River Economic Belt during 2011-2020 is greater than 1, and the overall average of each decomposition index is also greater than 1. This indicates that the technological innovation efficiency of industrial enterprises in the Yangtze River Economic Belt has generally improved based on the Malmquist index. In terms of regional comparison, the Malmquist index exhibits a "low-high-middle" spatial distribution. The up stream region has the lowest index (improved by 4.6%), the middle stream region has the highest index (improved by 9%), and the down stream region is in the middle (improved by 4.8%). It is also observed that the main source of improvement in the Malmquist index for all three regions is technological change. In addition, the overall trend of efficiency change follows a

Table 3. Malmquist Index Results by regions and provinces and municipalities

Regions/ provinces and municipalities		EC	TC	PEC	SEC	Malmquist Index
Up stream regions	Chongqing	1.002	1.034	1.000	1.002	1.036
	Sichuan	1.000	1.043	1.000	1.000	1.043
	Guizhou	1.004	1.073	1.000	1.004	1.077
	Yunnan	0.984	1.047	1.000	0.984	1.030
	Mean	0.998	1.049	1.000	0.997	1.046
Middle stream regions	Jiangxi	1.049	1.034	1.040	1.008	1.085
	Hubei	1.048	1.094	1.049	1.000	1.147
	Hunan	0.987	1.050	0.990	0.997	1.037
	Mean	1.028	1.059	1.026	1.002	1.090
Down stream regions	Shanghai	1.000	1.069	1.000	1.000	1.069
	Jiangsu	1.015	1.032	1.000	1.015	1.048
	Zhejiang	1.001	1.041	1.000	1.001	1.043
	Anhui	1.002	1.030	1.001	1.001	1.032
	Mean	1.005	1.043	1.000	1.005	1.048
Overall	Mean	1.008	1.050	1.007	1.001	1.058

"low-high-middle" spatial distribution. The up stream region has the lowest change (decreased by 0.2%), the middle region has the highest change (increased by 2.8%), and the down stream region is in the middle(increased by 0.5%).

As for technological change, it also exhibits a "low-high-middle" spatial distribution. The up stream region has the lowest change (increased by 4.9%), the middle stream region has the highest change(increased by 5.9%), and the down stream region is in the middle (increased by 4.3%).

Looking specifically at the provincial and municipality level, in the up stream region of the Yangtze River, Yunnan province had a decrease of 1.6% in both efficiency change and scale efficiency change. In the middle stream region, Hunan province experienced decreases of 1.3% in efficiency change, 1% in pure technical efficiency change, and 0.3% in scale efficiency change, but it had a significant increase of 5% in technological change. Jiangxi province and Hubei province saw increases of 4.9% and 4.8%, respectively, in efficiency change during the period of 2011-2020, and their technological changes increased by 3.4% and 9.4%, respectively. In the down stream region, Shanghai municipality, Jiangsu, Zhejiang, and Anhui provinces all showed improvements in various indicators, although the magnitude of improvement was not very large.

This suggests that the growth of technological innovation efficiency in the middle and up stream regions is unstable, indicating that it is still in the early stage of growth. On the other hand, the growth of technological innovation efficiency in the down stream region is relatively stable, indicating that it has entered a more mature stage of growth.

V. Conclusion

This article calculates and analyzes the efficiency of technological innovation in industrial enterprises in the Yangtze River Economic Belt and finds that the overall level of technological efficiency in this area during the period of 2011-2020 is relatively low. The Malmquist index shows an overall upward trend, with technological change being the main source of improvement. Moreover, significant differences exist among the upstream, middle, and downstream regions of the Yangtze River Economic Belt, as well as among different provinces and cities.

The Chinese government has formulated plans to support technological innovation in the Yangtze River Economic Belt [3] in order to overcome the efficiency differences in technological innovation among industrial enterprises in various regions. These plans provide specific guidelines for the development of technological innovation in the

Yangtze River Economic Belt. However, this article finds that differences still exist. Possible reason is that Sichuan Province, leveraging its energy and labor advantages, has developed into a leading manufacturing base in the central and western regions. Yunnan Province and Guizhou Province have long had relatively weak economies and lower technological levels. Although the government has increased investment in their technological innovation resources and achieved higher outputs, the stability remains uncertain. Hunan Province may rely on traditional industries such as steel, coal, and building materials, while the development of emerging industries has been slow, resulting in relatively weak innovation. Hubei Province benefits from its advantageous location, which has led to a developed shipping industry and the absorption of a large number of manufacturing industries relocated from the coastal areas. Additionally, Hubei Province has numerous universities and research institutes, which promote technological advancement and change. Shanghai, Jiangsu, and Zhejiang may have already entered a mature stage in terms of industrial structure, and their technological levels have reached a certain height, making it difficult for them to rapidly improve like some provinces and cities in the upstream and middle reaches of the Yangtze River.

Currently, China is facing various challenges and opportunities in the field of technological innovation. The study on the efficiency of technological innovation among industrial enterprises in the Yangtze River Economic Belt provides us with important references to deeply understand and respond to these challenges. However, due to the limited depth of this article, future research can be optimized in terms of research methods or indicator selection. Further exploration can be conducted to investigate the causes, evolutionary patterns, and spatial relationships underlying the efficiency differences in technological innovation among industrial enterprises in different regions of the Yangtze River Economic Belt. This will enable a more comprehensive assessment of the efficiency of technological innovation among industrial enterprises in the Chinese Yangtze River Economic Belt from 2011 to 2020.

REFERENCES

[1] Wang, H., "Xinhua News Agency Broadcast: General Secretary of the Communist Party of China, President of the People's Republic of China, and Chairman of the Central Military Commission Xi Jinping Presides over and Delivers an Important Speech at the Symposium on Promoting the Development of the Yangtze River Economic Belt in an All-round Way, " In Wang Hong, Executive Editor (Eds.), Yearbook of the Yangtze River, Yangtze River Yearbook Publishing, 2020.

[2] China Government Network, "Ministry of Science and Technology: Notice on Printing and Distributing the Plan for Transformation and Upgrading of Innovation-driven Industries in the Yangtze River Economic Belt," https://www.gov.cn/xinwen/2016-03/15/content_5053543.html

[3] Zhai, G. & Bai, X. S., "Research on Enterprise Capital Structure, Profitability, and Technological Innovation Capability: A Case Study of Shanxi Province and Central and Surrounding Provinces," Financial and Accounting Communication, No.36, pp.73-76, 2015.doi:10.16144/j.cnki. issn1002-8072.2015.36.020

[4] Jiao, L. Y., "Technological Innovation Investment and Firm Performance: An Empirical Analysis Based on China's Growth Enterprise Market Data," Contemporary Economy, No.20, pp.124-125, 2018.doi:cnki:sun:dajj.0.2018-20-055

[5] Jiang, B., "Empirical Study on the Efficiency Changes of Technological Innovation in China's Regional Large and Medium-sized Industrial Enterprises," Journal of Intelligence, No.2, pp.81-86, 2012.doi:cnki:sun:qbzz.0.2012-02-017

[6] Xie, L. L. & Xu, M., "Study on the Efficiency of Technological Innovation in Regional Large and Medium-sized Industrial Enterprises," Research on Science and Technology Management, No.6, pp.9-11+35, 2013.doi: cnki:sun:kjgl.0.2013-06-004

[7] Chen, W., Jing, R., Zhang, H. Q. & Hou, J., "Evaluation of Technology Innovation Efficiency of Large and Medium-sized Industrial Enterprises in Northeast China - Based on DEA-Malmquist Index Method," East China Economic Management, No.2, pp.66-71, 2017.doi:cnki:sun: hdjj.0.2017-02-009

[8] Li, X. J. & Yue, H. Z., "Research on Technology Innovation Efficiency and Convergence of Large and Medium-sized Industrial Enterprises in China," Investment Research, No.5, pp.139-148,

2017.doi:cnki:sun:tzyj.0.2017-05-012
[9] Hu, Y. & Zhou, L. Y. , "Research on innovation efficiency of high-tech industries in Yangtze River Economic Zone and its influencing factors,". Industrial Technology and Economics (06), 71-77. doi:CNKI:SUN:GHZJ.0.2018-06-009.
[10] Luo, F. & Wang, Y. Z., "Research on Technological Innovation Efficiency of Industrial Enterprises in the Yangtze River Economic Belt," Science, Technology and Management, No.6, pp.24-30, 2019.doi:10.16315/j.stm.2019. 06.008
[11] Bai, L. Z. & Qiu Y. L., "Measurement and Spatiotemporal Evolution of Technological Innovation Efficiency of Industrial Enterprises in the Yangtze River Economic Belt," Financial and Accounting Communication, No.18, pp.85-88, 2021.doi:10.161 44/j.cnki.issn1002-8072.2021.18.015
[12] Charnes, A., Cooper, W. W., & Rhodes, E., "Measuring the Efficiency of Decision Making Units," European Journal of Operational Research, Vol.2, Issue 6, pp.429-444, 1978. doi.org/10.1016/0377-2217(78)90138-8
[13] Farrell, M. J., "The Measurement of Productive Efficiency', Journal of the Royal Statistical Society, Vol.120, No.3, pp.253-290, 1957. doi.org/10.2307/2343100
[14] Kim, S. W. & Ma, L., "DEA model and industry efficiency analysis of foreign direct investment," Nankai Economic Research, No.5, pp.77-90. DOI:10.14116 /j.nkes.2007.05.008
[15] Färe, R., Grosskopf, S., & Logan, J., "The Relative Performance of Publicly-owned and Privately-owned Electric Utilities," Journal of Public Economics, Vol.26, Issue 1, pp.89-106, 1985.doi.org/ 10.1016/0047-2727(85)90040-4
[16] Caves, D. W., Christensen, L. R., & Diewert, W. E., "The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity," Econometrica, Vol.50, No.6, pp.1393-1414, 1982.doi.org/10.2307/1913388
[17] Xiao, W., & Lin, G., "Government Support, R&D Management, and Technological Innovation Efficiency: An Empirical Analysis Based on China's Industrial Sectors," Management World, No.4, pp.71-80, 2014.doi:10.19744/ j.cnki.11-1235/f.2014.04.008
[18] Bai, J., & Jiang, F., "Collaborative Innovation, Spatial Association, and Regional Innovation Performance," Economic Research, No.7, pp.174-187, 2015.doi:cnki:sun: jjyj.0.2015-07-014
[19] Chen, L., Zhang, L., & Huang, Y., "Patent Reports of China, the United States, Europe, Japan, and South Korea," Retrieved from http://blog.sciencenet.cn/u/feixiangfeixian

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