Research on the efficiency of technological innovation in patent-intensive manufacturing industry ——A case study of Shanghai, China

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Abstract: Patent-intensive industries are an important support to ensure the high-level development of China's innovation capacity, and their industrial transformation has a major impact on the improvement of China's independent innovation capacity. Taking Shanghai, China, as an example, this paper puts forward a research framework for the efficiency of technological innovation in patent-intensive manufacturing industry, and uses AHP and DEA-Malmquist index method to select three first-level indicators such as innovation resources and nine second-level indicators such as R&D investment to build an evaluation index system for the efficiency of technological innovation in patent-intensive manufacturing industry. The AHP model was used to determine the weights of the index system, and the DEA-Malmquist index method was used to calculate the panel data for six patent-intensive manufacturing industries in Shanghai from 2017 to 2021. The degree of technological innovation in Shanghai's six patent-intensive manufacturing industries was analyzed over a five-year period. Finally, the countermeasures and proposals are proposed to improve the efficiency of technological innovation in the patent-intensive manufacturing industry in the region and increase the market competitiveness of the patent-intensive manufacturing industry.

Keywords: Patent intensive manufacturing; Technological innovation efficiency; AHP； DEA- Malmquist index method; Shanghai

1 INTRODUCTION

Technology and innovation are driving the sustainable development of the national economy as the economy and technology become more global. In April 2012, the U.S. Department of Commerce and the U.S. Patent and Trademark Office issued the report "Intellectual Property and the U.S. Economy: An Industry Focus", in which IP-intensive industries were first introduced, and since then, several countries have conducted studies on IP-intensive industries[4]. China has been conducting statistical research and local pilot work on IP-intensive industries for many years since 2012, and in April 2014, the China Intellectual Property Office officially published its latest research result, "China Regional Industry Patent Intensity Statistical Report", which puts forward the concept of highly patent-intensive industries from the perspective of patents[6]. Since then, drawing on the measurement methods of the United States and the European Union on intellectual property (patent) intensive industries, on April 1, 2019, the National Bureau of Statistics of China released the China Statistical Classification of Intellectual Property (Patent) Intensive Industries.

EMIS 2023, February 24-26, Chengdu, People's Republic of China

DOI 10.4108/eai.24-2-2023.2330678

As a result, patent-intensive industries promote national and regional economic development, and technological innovation activities can significantly strengthen the competitiveness of patent-intensive industries. Most existing scholars have studied patent-intensive industries from the perspective of innovation efficiency, impact factors, and innovation performance. Jiang Nan investigated the differences in innovation efficiency systems between patent-intensive and non-patent-intensive industries in China through different year spans [2]. On this basis, the changes in R&D performance of the two industries are evaluated [3]. CAO's study of innovation performance and innovation patterns in patent-intensive industries found low innovation efficiency and significant variation in innovation patterns in this industry [1]. Keith et al. found that patent rights can positively affect the R&D intensity of patent-intensive industries and that patent protection increases the R&D capacity of patented industries [5].

From the existing studies, certain results have been obtained on the efficiency and influence factors of patent-intensive industries has achieved certain research results. In this paper, based on the previous research, AHP and DEA-Malmquist index method are used to conduct an in-depth study on the technological innovation efficiency of patent-intensive manufacturing industry, and the panel data of patent-intensive manufacturing industry in Shanghai, China, from 2017-2021 are processed to determine the weight of each index through AHP hierarchical analysis; the key indicators were selected for DEA analysis to derive the performance data to explore the improvement paths for patent-intensive manufacturing industries in the region and improve policy recommendations to promote the development of patent-intensive manufacturing industries in the region.

2 RESEARCH DESIGN

2.1 Constructing the index system

In this paper, we use the hierarchical analysis method (AHP) to measure the weights of factors influencing the technological innovation efficiency of patent-intensive manufacturing industries. By using YAHAP software to construct the hierarchical structure of technological innovation efficiency of patent-intensive manufacturing industry, we consider the multiple subjects of enterprises, market and government, and set three evaluation criteria based on expert consultation and research, including innovation resources, knowledge creation and enterprise innovation, and then set a total of nine index systems according to each criterion, as shown in Table 1：

Table 1: Influencing factor index system

Evaluation Criteria	Indicator System
Innovative Resource Factors A_1	R&D investment A_{11}
	Government Funding A_{12}
	R&D Personnel Full-Time Equivalent A_{13}
Knowledge creation factors B_1	Total Patent Applications B_{11}
	Number of effective invention patents B_{12}
	Number of invention patents granted to 10000 researchers B_{13}
Business Innovation Factors C_1	New product sales revenue C_{11}
	Technology introduction costs C_{12}
	Technology introduction, digestion and absorption capacity C_{13}

2.2 Consistency testing of indicators

First a judgment matrix A_0 is constructed for each of the three dimensions of the criterion layer, followed by judgment matrices A_1-A_3 for each of the indicator layers, and finally conduct a consistency test.

Saaty introduced a random consistency index RI to measure relative consistency, with the consistency ratio set is CR=CI/RI. If CR<0.1, the matrix A is considered to have passed the consistency test and the weight values can be confirmed, otherwise the data are invalid. For the overall objective of increasing the efficiency of technological innovation in patent-intensive manufacturing industries, the impact factors and the consistency test results for each matrix are shown in Table 2:

Table 2: Consistency test results

Determining Matrix Classes A	Maximum characteristic root λ_{max}	Consistency testCR
A_0	3.0735	0.0707
A_1	3.0026	0.0025
A_2	3.0385	0.0370
A_3	3.0858	0.0825

2.3 Indicator weighting calculation results

According to the arithmetic results of the YAHAP software, the weights of the evaluation criteria for innovation resources, knowledge creation and enterprise innovation are 11.72%, 61.44% and 26.84%, respectively. The results show that the knowledge creation of enterprises plays an important role in measuring the level of achievement of the overall target, and that corporate innovation is an important factor in improving the efficiency of technological innovation in patent-intensive manufacturing industries. Although the overall index weighting of the innovation resource factor is not high, the new product sales revenue and technology introduction, digestion and absorption capacity in the detailed indexe should also be noted. The detailed weights of each index system are shown in Table 3：

Table 3: Weighting of influencing factors

Evaluation Criteria	Weights	Indicator	Weights
		A_{11}	3.43%
A_1	11.72%	A_{12}	1.08%
		A_{13}	7.21%
		B_{11}	39.14%
B_1	61.44%	B_{12}	15.87%
		B_{13}	6.43%
		C_{11}	18.08%
C_1	26.84%	C_{12}	6.05%
		C_{13}	1.08%

The results in the hierarchical analysis method show that there are three index factors with weights higher than 10%: total number of patent applications B11 (39.14%), new product sales revenue C11 (18.08%), and the number of valid invention patents B12 (15.87%). The total number of patent applications is an important factor in promoting the efficiency of technological innovation in patent-intensive manufacturing industries. A high total number of patent applications indicates, to some extent, a higher innovation capacity of the society and reflects an active level of technological development activities, but a high number of patents without high patent quality is not beneficial to the economic value of society and industry. Therefore, while increasing the number of patent applications, the patent-intensive manufacturing industries should strengthen the quality of patent applications. New product sales revenue, a representative indicator of the level of marketization of industrial innovation, can reflect the effective economic benefits that patent-intensive manufacturing industries receive through innovation activities. At the same time, there is a lag between the filing of patent applications and their validity, and some patents have a short life span due to the lack of utility or commercialization, and the number of patents in the industry is in a dynamic state of change.

3 ANALYSIS

3.1 Selection of indicators

A model of the efficiency of technological innovation in patent-intensive manufacturing industries is constructed, where the input indicators reflect the resources of technological innovation in patent-intensive manufacturing industries, and the expenditure indicators reflect the effect of technological innovation in each patent-intensive manufacturing industry. Combining the three indicators with more than 10% weight obtained by the AHP method, the total weight reaches 73.09%, which better reflects the main information of the index system. For the selection of input metrics, the study selected two traditional and authoritative metrics: R&D level and technology related metrics. Of these, the R&D personnel are all equivalent, the internal expenditure of R&D funds and the number of R&D projects respectively reflect the level of human, financial and industrial innovation activities in the innovation activities of patent-intensive manufacturing industry respectively; the technology introduction costs can reflect the level of external spending by industrial innovation funds, which is an important reflection of the level of investment in patent-intensive manufacturing industries by technological innovation funds. The indicator of output variable is choose from the three indicators with weighst of 10% or more in the AHP method. In summary, the input-output indicators selected for the study are shown in Table 4：

Table 4: Green technology innovation efficiency input and output indicators

Indicator	
Input Indicators	R&D Personnel Full-Time Equivalent
	Internal expenditure on R&D funds
	Number of R&D projects
	Technology introduction costs
Output Indicators	Total Patent Applications
	Number of effective invention patents
	New product sales revenue

3.2 Sample and data

The study selects panel data of six major categories of patent-intensive manufacturing industries (information chemical manufacturing (ICM), pharmaceutical manufacturing (PM), aerospace instrument manufacturing (AIM), electronic and communication equipment manufacturing (ECEM), electronic computer and office equipment manufacturing (ECOEM), and medical equipment and instrumentation manufacturing (MEIM)) in Shanghai, China, from 2017 to 2021 as the sample. The data are mainly obtained from China Statistical Yearbook (2018-2022), China High Technology Industry Yearbook (2017, 2019, 2020, 2021), and Shanghai Statistical Yearbook (2018-2021).

3.3 Empirical results

（1）Descriptive Statistical

The input and output indicators themselves selected for the study are representative of the importance and trends of innovation over a five-year period in the six patent-intensive manufacturing industries. Therefore, the study performed a descriptive analysis before measuring the efficiency of technological innovation, and the results are presented in Table 5 below：

Table 5: Descriptive analysis of input-output indicators

Indicator	R&D Personnel Full-Time Equivalent		R&D investment		Number of R&D projects	
Year	2017	2021	2017	2021	2017	2021
Min	0.72	1.32	5746.23	4646.42	36	39
Max	5.16	6.07	796544.37	9936556.54	1762	1478
Mean	2.56	3.065	232679.04	259985.30	700.17	664.67
SD	1.57	1.62	286570.83	340073.04	711.46	632.62
Indicator	Technology introduction costs		Total Patent Applications		Number of effective invention patents	
Year	2017	2021	2017	2021	2017	2021
Min	17.25	14.08	3767	105	82	134
Max	31209.47	32567.88	57	5371	6453	9785
Mean	5932.14	6152.2	1023.66	1509.33	1547	2406.5
SD	12411.25	12964.87	1380.87	1945.27	2441.09	3669.03
Indicator	New product sales revenue					
Year	2017			2021		
Min	107671.23			74081.88		
Max	14355460.92			15896828.69		
Mean	3645199.415			4102853.973		
SD	5304718.00			5861153.64		

From Table 5, it can be observed that both the full-time equivalent of R&D personnel and internal expenditure of funds have increased in 2021 compared to 2017, indicating that the importance and investment in R&D has increased in the six patent-intensive manufacturing industries in Shanghai. The cost of technology introduction has also increased to some extent with time. At the same time, with the strong support and focus on IPR in China, both indicators related to patents have increased significantly, indicating that the Shanghai industries have paid

sufficient attention to IPR protection. As a result of the overall increase in the number of input indicators, the measure of revenue from sales of new products, which is a measure of output, also gradually increased. From the descriptive analysis of the index data, it can be seen that the input and output indicators of the patent-intensive manufacturing industries show a good upward trend from 2017 to 2021, but the benefits of resource utilization still need to be analyzed in depth through further measurements.

（2）Results

Based on the above collected data, the Malmquist index model was applied and DEAP2.1 software was used to derive the evaluation results on the efficiency of technological innovation in patent-intensive manufacturing industries in Shanghai, China, as shown in Table 6：

Table 6: Patent-intensive manufacturing industry Technology Innovation M Index

Year	EFFC	TECHCH	PECH	SECH	M Index
2017-2018	0.976	1.028	1.000	0.976	1.00
2018-2019	1.025	1.279	1.000	1.025	1.31
2019-2020	0.991	0.866	1.000	0.991	0.86
2020-2021	0.976	1.191	1.000	0.976	1.16
Mean	0.992	1.079	1.000	0.992	1.07

Table 6 shows that the M-index of technological innovation in patent-intensive manufacturing in Shanghai, China, in 2019-2020 is less than 1,indicating that the technological innovation in patent-intensive manufacturing in Shanghai as a whole is showing continuous progress. Meanwhile, Shanghai has responded to the call of the Chinese government to attach importance to industrial innovation and accelerate the development of patent-intensive manufacturing, but the small change in the technological progress index (TECHCH), which is influenced by the lagging scale efficiency of technology level, hinders the rate of progress of technological innovation efficiency. The small change in the index of technical efficiency change (EFFC) in 2017-2021 indicates a positive relationship between technical efficiency change and technological innovation efficiency. In addition, the data of pure technology level (PECH) and scale efficiency change (SECH) reveal that the pure technology level promotes the growth of technical efficiency.

The study was conducted to further explore the technological progress of six patent-intensive manufacturing industries in Shanghai from 2017 to 2021 from a dynamical perspective, as measured by the DEA- Malmquist index. The results are shown in Table 7：

Table 7: Total factor productivity results of the six patent-intensive manufacturing industries in Shanghai

Year	Result	ICM	PM	AIM	ECEM	ECOM	MEIM	Mean
2017-2018	TFPCH	0.839	1.037	1.170	0.984	1.064	0.954	1.003
	TECHCH	0.839	1.203	1.170	0.984	1.064	0.954	1.028
	PECH	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SECH	1.000	0.862	1.000	1.000	1.000	1.000	0.976
2018-2019	TFPCH	1.968	1.289	1.267	1.196	1.080	1.222	1.311

2019-2020	TECHCH	1.968	1.111	1.267	1.196	1.080	1.222	1.279
	PECH	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SECH	1.000	1.160	1.000	1.000	1.000	1.000	1.025
	TFPCH	0.703	0.960	0.780	0.832	0.791	1.156	0.858
	TECHCH	0.703	1.014	0.780	0.832	0.791	1.156	0.866
	PECH	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SECH	1.000	0.946	1.000	1.000	1.000	1.000	0.991
2020-2021	TFPCH	1.291	1.012	1.264	1.129	1.287	1.024	1.162
	TECHCH	1.291	1.173	1.264	1.129	1.287	1.024	1.191
	PECH	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SECH	1.000	0.863	1.000	1.000	1.000	1.000	0.976
Mean	TFPCH	1.20025	1.0745	1.1202	1.0352	1.0555	1.089	1.095
	TECHCH	1.20025	1.1253	1.1202	1.0352	1.0555	1.089	1.104
	PECH	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	SECH	1.000	0.9578	1.000	1.000	1.000	1.000	0.993

According to the results in Table 7, the total factor productivity (TFPCH) of the six patent-intensive manufacturing industries in Shanghai is greater than 1, and the average value of the industry is 1.095, which indicates that the innovation productivity of the six patent-intensive manufacturing industries in Shanghai is growing significantly and the innovation capability of the industry is steadily improving. Among them, the total factor productivity (TFPCH) of information chemical manufacturing industry is the highest at 1.20025, and the total factor productivity (TFPCH)of pharmaceutical manufacturing industry is the lowest at 1.0745. The difference between the maximum and the minimum is 0.12575 units. In addition, the mean value of the technological progress index (TECHCH) of the six patent-intensive manufacturing industries is 1.104, indicating that the progress of technological level has a positive contribution to the improvement of technological innovation efficiency of patent-intensive manufacturing industries in Shanghai. Observing the scale efficiency (SECH) of each manufacturing industry in five years, we can find that the scale efficiency (SECH) of some industries at a certain event point is less than 1.000, for example, the scale efficiency (SECH) of pharmaceutical manufacturing industry in the three years of 2017-2018, 2018-2019 and 2019-2020 are 0.862, 0.946 and 0.863, respectively. It indicates that while the input of innovation in the industry has increased during the three years, the output of innovation in the industry has not reached the optimal size of the industry, and it is still in the state of increasing industry size.

4 CONCLUSION and DISCUSSION

In this paper, we identify three primary indicators and nine secondary indicators for assessing the efficiency of technological innovation in patent-intensive manufacturing industries, based on the national innovation capability evaluation index system, and construct an evaluation index system for the efficiency of technological innovation in patent-intensive manufacturing industries. The measured results show that the technology innovation index of this patent-intensive manufacturing industry is well evaluated and has high credibility. The weights of the index system were determined by using the AHP cascade analysis, and three core indicators were selected to analyze the efficiency of technological innovation in patent-intensive manufacturing industry in Shanghai by using the DEA- Malmquist index method.

Empirical results show that the efficiency of technological innovation in patent-intensive manufacturing industries in Shanghai, China, has shown an overall trend of growth during 2017-2021 period, indicating that the level of innovation technology in the industry has improved. In 2021, the gap between the efficiency of technological innovation in Shanghai's six patent-intensive manufacturing industries has narrowed compared to 2017, but the input and utilization of innovation resources still needs to be further improved. Meanwhile, the average value of the total factor productivity of Shanghai's patent-intensive manufacturing industries over the five-year period is greater than 1, indicating that the innovation capacity of the city's patent-intensive manufacturing industries is in a steady state of improvement. In addition, the average value of the technological progress index (TECHCH) of each manufacturing industry is above 1.000, which indicates that the technological level of patent-intensive manufacturing industries in Shanghai is always in a growing situation.

In order to raise the level of technological innovation efficiency of patent-intensive manufacturing industries in the region, the following three countermeasures are proposed.

（1）Enterprises should balance resource input and output, strengthen cooperation with universities, and promote the transformation of market results.

（2）The government should create a pilot zone for collaborative development of patent-intensive manufacturing to improve the efficiency of scientific and technological innovation output.

（3）Enterprises should strengthen the construction of talent training system, pay attention to the importance of higher education for talent training, and build high precision talents through the formation of patent-intensive industrial alliances.

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